AMERICAN

Industrial Hygiene

ASSOCIATION

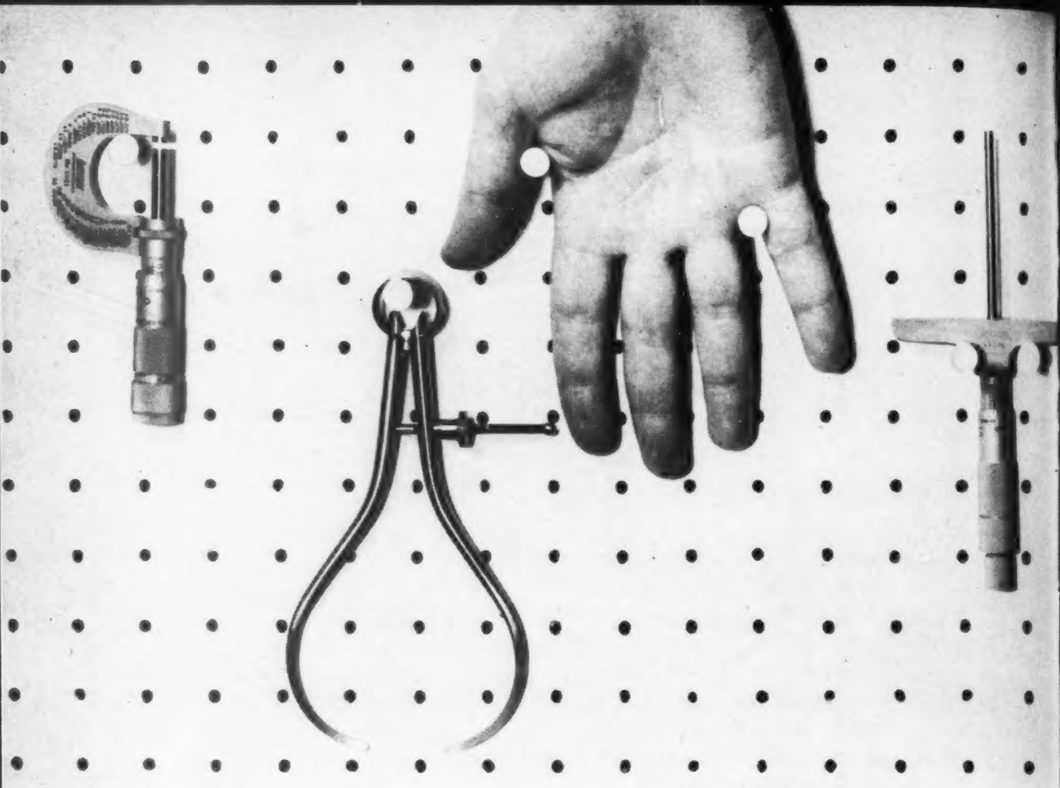
Quarterly

VOLUME 16, NUMBER 2
JUNE, 1955

AMERICAN
INDUSTRIAL HYGIENE
ASSOCIATION
Quarterly

Volume 16 JUNE, 1955 Number 2

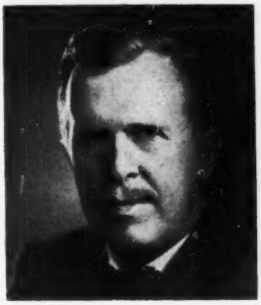
AMERICAN INDUSTRIAL HYGIENE ASSOCIATION QUARTERLY, published by the American Industrial Hygiene Association in March, June, September, and December. HOWARD N. SCHULTZ, Editor; HERBERT J. WEBER, Advisory Editor; LLOYD E. GORDON, Associate Editor; JAMES A. MARTIN, Advertising Editor; CHARLES WYMAN, Circulation Editor; A. D. CLOUD, Publisher; DORIS FLOURNOY, Editorial Assistant. Publication and Editorial Offices, 605 North Michigan Avenue, Chicago 11, Illinois. Subscription $4.00 per year in the United States; $4.50 per year in Canada; $5.00 per year in other countries. Single copies, $1.50. Entered as second class matter May 3, 1948, at the post office at Sheboygan, Wisconsin, under the Act of March 3, 1879. The AMERICAN INDUSTRIAL HYGIENE ASSOCIATION QUARTERLY reserves the right to edit all advertisements and to refuse advertising copy when it does not meet the high professional standards adopted by the Association.



The Experimental Animal—Man —in Industrial Hygiene

The Donald E. Cummings Memorial Lecture

JAMES H. STERNER, M.D., Rochester, New York



James H. Sterner, M.D.

IN THE PRESENT evolutionary stage of industrial hygiene, the problems arising from an increasingly complicated industrial technology have become so intense and so complex that the general practitioner of industrial hygiene is fast giving way to the specialist. Of course, we are not the only discipline which is undergoing this transition. Perhaps we should be less surprised since in most other branches of scientific endeavor, specialization usually occurs only after a common, basic training period, a trunk from which the branches of specialization diverge.

In contrast, in industrial hygiene, a reflection on the antecedents of many of the leaders shows little in common, so far as formal technical training. One may have arrived from a background of chemistry, another from engineering, still another from geology, and, it may be proper to add, from medicine. I don't know of anyone in our profession who arrived via the ministry, but there have been times when I felt that a Doctor of Divinity might have had a better solution for the problem than the one I was capable of offering. The common denominator for these individuals in industrial hygiene developed after they had finished their formal training. It is always a source of wonder to me that as complex and diverse a subject as the multiplicity of health hazards found in our factories, mills, and mines could produce among individuals with such varied backgrounds a common way of thinking and acting.

Many of us have viewed with concern the trend in industrial hygiene toward specialization, chiefly, I think, because it means a possible loss of the free and informal interchange of ideas from many disciplines, a condition which prevailed in the early meetings of this Association and to which many of us, who came into industrial hygiene without formal orientation, owe so much for what little understanding we may have acquired. In our nostalgia, however, we are apt to confuse the purely intellectual rewards with the undeniable pleasure of the friendships which developed.

It might even be alleged that we huddled together for the warmth of mutual appreciation, for at times this seemed to be our only source of recognition.

The demands of this ever more complicated industrial technology and of the diversity of incident physical and chemical hazards, has brought about a considerable increase in the number and variety of people required to control these problems. We now recognize the industrial hygiene chemist, the industrial hygiene engineer, the industrial toxicologist, the health physicist, the industrial hygiene physician, and, more recently, the air and water pollution expert, as separate and distinct categories of what we once called an "industrial hygienist."

The many benefits of this specialization

Presented at the Sixteenth Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, Buffalo, New York, April 27, 1955.

are obvious, but we must provide a fluid and effective means of communication between the chemist, the engineer, the physicist, the toxicologist, the physician, and the other specialists brought into industrial hygiene. There must result from this interchange of ideas not only an appreciation of each team member's contribution, but an ability actually to bridge the gap between the disciplines, to synthesize, from the offerings of each of the fields, the solutions to the ever more complicated problems. Each member specialist must not only contribute the information he is most qualified to give, but also must encourage a sympathetic, intelligent, and mutual understanding.

My subject, "The Experimental Animal, Man, in Industrial Hygiene," was selected with several purposes in mind. First, the major part of my work has been directly concerned with this subject, and if I am to follow the admonition and recommendation made above concerning the sharing of knowledge among the industrial hygiene team, this would seem to be my proper contribution. Second, and here there is ulterior motivation, the subject is sufficiently broad to permit the inclusion of some ideas which do not seem appropriate for the usual scientific paper, but which I believe may be of mutual interest and value, and proper on this occasion.

The animal species, *homo sapiens*, or man, has been an experimental subject in occupational exposures from the very beginning of activities which could be called an occupation. The recognition of the existence of toxic fumes and dusts associated with work in mines and smelters extends back many centuries. In each era, the monetary value of the man, at first in terms of replacement, largely determined to what extent the crude control measures were applied—in some cases by limiting the working time, in others by rudimentary filters worn over the nose and mouth, and later by the beginnings of specific ventilation devices. These exposures, like the ones encountered in industry today, were incidental or accidental, an unwanted and objectionable by-product in the making of things to enhance man's standard of living.

An equilibrium is established between the desire to transmute the natural resources into useful things and the penalty which seems to be coincidentally and inexorably exacted by occupational injuries and disease. The cost of these disabilities, originally born solely by the workman, is now generally accepted, in major part, as a proper charge against cost of production, and is added to the selling price of the goods. A growing and impelling social concern for human suffering has added appreciably to the monetary motivation for controls, and by changing the emphasis from compensation to prevention has stimulated the growth of industrial hygiene. The fact that the costs may appear in the engineering or operating expense as ventilation equipment or process modification rather than compensation payments for the injured workman does not really change the basic character of this equilibrium.

The concept that man in his occupational environment is the subject of a continuing industrial hygiene experiment may seem absurd, or at least novel. Certainly the workman in the plant, particularly if environmental factors are reasonably well controlled, does not usually consider himself an experimental subject. When one reflects, however, on the history of threshold limits, it becomes apparent that many of our present standards have resulted from just such a succession of experimental events.

A pattern which has been repeated many times, begins with the introduction of a new industrial substance and an apparent assumption that it will be innocuous under the conditions of use. If injurious effects are observed in the exposed workmen, an effort is made to reduce the exposure. Then follows another trial period at this reduced level. If injury is again noted, a still further reduction is made, and so through a series of step-wise trials until a set of conditions is reached which is acceptable.

The criteria for such acceptability are constantly being modified under the influence of changing social attitudes, the recognition of the effect of discomfort on productive capacity, and the identification of delayed or obscure injury as our diagnostic procedures become more acute. Thus since the assumed acceptable threshold limit of today may require modification as further data develop, the experiment is never ended. Even in the situation where an industrial substance has never been

known to cause an injury, the element of the experiment is present. Here a description of the circumstances under which the safe handling has occurred would essentially define a kind of threshold limit for that material, and the absence of a scientific observer does not negate the element of experimentation.

Many perplexing problems are encountered in the study of our experimental subject, man, in relation to his occupation. Some of these problems have recurred with such frequency, certain of his complicating behavior patterns have appeared so repeatedly, as to signal their importance. The difficulties in achieving an understanding are not due solely to the peculiarities of the experimental subject, but in many instances are a direct result of the fact that the observer or investigator is susceptive to the same characteristics and limitations.

Of these recurring and complicated problems, the one dealing with individual susceptibility is as common and as confused as any. The basic relations, as defined by purely objective data are not simple, but have been confounded by ignorance and sloven thinking, and on occasion, by deliberate distortion. In the practice of industrial hygiene, the standards of acceptance for an occupational disease are those established on good epidemiological principles. There are two sources of information which do not seem to require such critical criteria, which sometimes take extreme liberty with scientific credibility, but which may exert an influence far beyond their basic merits. The first of these is the case report, frequently an isolated observation, without quantitative measurements of environmental factors, and by an observer who has had little or no previous experience with intoxications of this type.

A considerable number of these cases involve an uncommon or poorly defined syndrome, which if occurring in a person without significant exposure would be accepted as idiopathic, or having no recognized cause. I have seen a reliable physician ignore a long course of therapy with sulfa drugs, followed by a mixture of antibiotics, and focusing attention on an exposure to an industrial chemical, attribute an obscure vascular disease to this latter single factor. This, in spite of the fact that experience with the industrial compound had included many individuals at greater levels of exposure without a single untoward reaction.

The second area in which epidemiological principles are frequently ignored is in workmen's compensation cases. We would agree that "the benefit of the doubt" should be given to the workman, but believe that a greater distinction should be made between the terms "possible" and "probable." At least, the social pressures and legal obfuscation, which weigh heavily in these determinations, should be recognized as such and the alleged relationship judged on more objective factors.

It is always confusing to hear a physician extend the concept of individual susceptibility far beyond that which he adopts in his daily administration of medications. In practice, the physician has little hesitation in giving a dose of medicine which is one-tenth or one-twentieth of the lethal dose, and excepting in infrequent cases of sensitization or allergy, serious toxic reactions rarely occur. His experience, and that gained from the experience of other physicians in administering drugs, place relatively narrow limits on individual susceptibility. His testimony on the effects of industrial chemicals is too frequently based on a different set of standards. The significance of single case reports and of workmen's compensation decisions in summary articles must be critically scrutinized.

A perennially recurring problem that is posed in many forms, involves the substitution or supplement of a program for limiting exposures through usual industrial hygiene techniques, by the feeding or administration of a food element or other chemical. The proposals have ranged from milk for lead poisoning or zinc chills, to vitamins for a variety of possible ills, to a more modern supplement of complexing or chelating agents, as an *hors d'oeuvre* for lead intake. The majority of the proposed items can be dismissed as having no beneficial effect in these circumstances. In fact, in one instance, encountered early in my experience, an unexpected and opposite result occurred. A lead burner, reporting for an examination, asked bluntly, "Can't I stop taking that damned milk?" It developed that for a number of years the lead burners in the plant had been required to drink a ra-

tion of milk, supplied by the company. (I never could find out how it started.) Things went well for a long time until a new supervisor, eager to do the right thing in protecting his men, developed the reasonable idea that if a quart of milk a day was good, four quarts was very much better. And four quarts, drunk under the zealous eye of the new group leader, was sufficient to impair the appetite. The affair wasn't a complete loss, however, as the complainer in this instance lost six pounds of some 40 he should have lost anyway. The real fallacy though—in fact the real danger—in the use of protective factors of this type lies in the substitution of a questionable or possibly harmful device for dealing with an excessive intake of a toxin rather than emphasizing the prevention of that intake by effective industrial hygiene controls.

An essential factor in the study of man in his industrial setting, is a set of normal values for each of the characteristics which may be needed to evaluate possible harmful effects.

One of my first disillusionments in this field was an attempt to apply norms obtained from medical textbooks to the industrial population under study. It should have been obvious that data for blood counts obtained from 86 "normal" medical students would not be suitable for comparison with a population in an industrial plant. It took more experience to learn that data from industrial populations in different parts of the country were not unrestrictedly interchangeable. Even the reporting of such findings can be hazardous. On one occasion in presenting a picture of an industrial population to a Southern medical society, I compared data on red cell counts obtained in New York State and in Tennessee. The New York State erythrocyte count average was 300,000 greater than that of Tennessee. The possible explanation that differences in diet or more effective general preventive measures accounted for the discrepancy was acceptable to the society, but I made a grave error in my conclusions in stating specifically that "the men of the North were more red-blooded than the men of the South."

In developing norms on an industrial population one is impressed with the greater variability of many characteristics than medical school teaching would indicate. Since people at work are in varying states of health, the industrial population norm will include subjects with diabetes, heart disease, arthritis, and a host of other conditions which are not "normal" in the usual sense of meaning "free from disease." The physician who is new to industry frequently is surprised by the number of people with significant pathology of long standing who are, nevertheless, free from any symptoms, capable of performing a good day's work, and who show normal values for a variety of laboratory tests.

Recently a proposed safe practice bulletin on benzene recommended that individuals with white blood cell counts less than 5,000, and more than 10,000, be excluded from work with this solvent. Distribution values for leukocyte counts obtained in our studies on industrial populations in the east, south, and far west, would indicate that such criteria are too rigid, and that many normal individuals would be excluded, needlessly, from work involving this exposure.

Not all of the variability in such data is due to the subject material. Many of our clinical laboratory techniques have a considerable inherent variability—and to this must be added the variability due to the technician. We have observed a number of instances in which a statistically significant result just wasn't so. In one important instance, the "trend," initially interpreted as due to a toxic reaction, was actually the result of the fading of a colorimeter filter. In another case, with a significant "trend," the prolongation of the test period and a new set of technicians resulted in a quite different conclusion from that which would have been made if the study had been terminated a year earlier. After the repetition of such experiences, one becomes conservative in drawing conclusions from limited data, and perhaps hypercritical of single surveys without adequate controls.

The area in which our human subject differs most radically from the lower species is in the matter of emotional response, and it is with this characteristic that the investigator of behavior in the industrial milieu has his greatest difficulty. The criteria of what constitutes a "safe and healthful" industrial environment have come to depend more and more upon factors with a strong

subjective component, such as "discomfort." The problem immediately becomes complicated by elements which resist objective analysis, such as attitudes, motivations, and prior conditioning. It is not unusual to find, in one situation, individuals working without protest under conditions which seem highly objectionable to an impartial observer, and in another, to see a violent explosion over a really inconsequential and minor annoyance. An example of the former is the tolerance displayed by workmen, acclimated through long experience, to acetic acid vapor concentrations of 20 to 30 parts per million. Such a level provokes a marked cough response and lacrymation in the uninitiated. In contrast, the introduction of a solvent at an exposure level far below any critical concentration, produced in one department an epidemic response of nausea and vomiting—even though this same material had been used without any complaint or observed effects for several years, and under more adverse circumstances, elsewhere in the same building.

Several of the chlorinated hydrocarbons possess odors which many people find objectionable. Nausea is not an uncommon response to levels of ethylene dichloride well below a concentration which can be judged harmful by any objective test. Nor does an individual's adverse response to one odor permit an estimation of the effect of another.

An employee of the cafeteria department reported to me, stating that in the past six weeks he had lost 12 pounds. It developed that during this time he had been assigned to the job of collecting the garbage, and almost immediately reacted by repeated attacks of nausea and vomiting. He had not complained to his supervisor, but the latter observed him being ill, and referred him to the Medical Department. The man recognized that the symptoms were on a psychological basis, but said he could not control them. Here was an occupational disease on a purely psychological basis, but with an objective result—the symptoms and the loss of weight.

The only job to which he could be transferred at the time involved an exposure to ethylene dichloride. With some misgivings the transfer was made, with the provision that he report to me at frequent intervals. Much to our surprise, he had no further symptoms, regained the weight, and for the period of several years in which I followed him, was most enthusiastic about his job, odors and all.

We, in industrial hygiene, cannot help but wonder at times, just how great is our impact upon the whole universe of health problems created by an ever more complicated and expanding industrial technology. As with our friends in safety work, the more effectively we do our jobs, the less apparent need there is for our services. It is paradoxical that our job security sometimes seems to depend upon the occurrence of a few cases of intoxication, when these really may be evidence of the failure of our efforts. Unfortunately in industrial hygiene, we do not have comparable indices of performance such as accident frequency and severity rates. We can take some comfort in adding up the tons of toxic materials which are used and noting that no occupational disease occurred in the individuals exposed, but this is apt to have real significance only to another industrial hygienist.

In 1911, the life span of the industrial worker was nearly seven years shorter than that of the general population. This gap has been closed during the intervening years, so that now the worker in industry can look forward to a longevity at least equal to that of his non-industrial friend. This fact, reported by the Metropolitan Life Insurance Company, should be a major source of satisfaction to all of us in industrial health work. It can be interpreted only that this dramatic improvement, which took place during a period when tremendous sources of hazardous physical and chemical agents were introduced into the industrial environment, could not have occurred without a coincident, vigorous, and substantial development of industrial hygiene.

Man continues in his role as our most important experimental subject, and will inevitably do so as long as new chemical substances, new physical agents are found useful in supplying the goods and services which he wants. In this experiment, the goal of industrial hygiene must not be limited to the prevention of overt occupational disease, but must accept the challenge to achieve an environment which is truly "safe and healthful."

Potential Radiation Hazards

in the use of x-ray diffraction equipment

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ONE OF THE FUNCTIONS of the AEC Health and Safety Laboratory is to assist AEC contractors in the evaluation of radiation protection problems. During 1953 and 1954, Radiation Branch representatives surveyed eight x-ray diffraction units of various manufacture (three commercial makes). The primary purpose of the surveys was to determine whether these units comply with the American Standards Association "Safety Code for the Industrial Use of X-Rays" in accordance with AEC standards.[1] It was also of interest to observe if compliance with the Code would unduly limit the particular research program.

Equipment

THE X-RAY UNITS surveyed were generally operated at about 35 to 50 kilovolts (kv.) and 10 to 40 milliamperes (ma.). Diffraction patterns are obtained by photographic methods. A typical fluorescence analysis procedure involves the study of characteristic radiation from a metallic or mineralogical specimen (Fig. 1). That is, the primary x-ray beam is permitted to impinge on the specimen, thereby producing characteristic secondary radiation, which, after passing through parallel slits, strikes a crystal. The intensity of the characteristic radiation of the specimen reflected by the crystal is then measured by a GM or scintillation counter located at various angles with respect to the crystal. The elemental composition of the specimen can be inferred from a knowledge of the spectrum as characterized by maximum counting rates at various angles, and a standard calibration.

The total radiation spectrum, for the purpose of this discussion, consists of several components.

1. Primary x-rays originate in the x-ray tube target (e.g. tungsten, molybdenum) with the useful beam emerging from the tube window.
2. Some of the primary radiation may penetrate the tube shield as leakage radiation. In low voltage x-ray equipment, this component is generally unimportant.
3. Secondary radiation results from the interaction of the useful beam with the specimen.
4. Stray radiation comprises scattered radiation produced by the interactions of the primary and secondary beams with the various components of the x-ray diffraction equipment, plus any leakage radiation.

The intensity and distribution of the scattered radiation changes with the orientation of the GM or scintillation counter. The energy spectrum of the secondary radiation varies according to the specimen under study. Similarly, the x-ray tube tar-

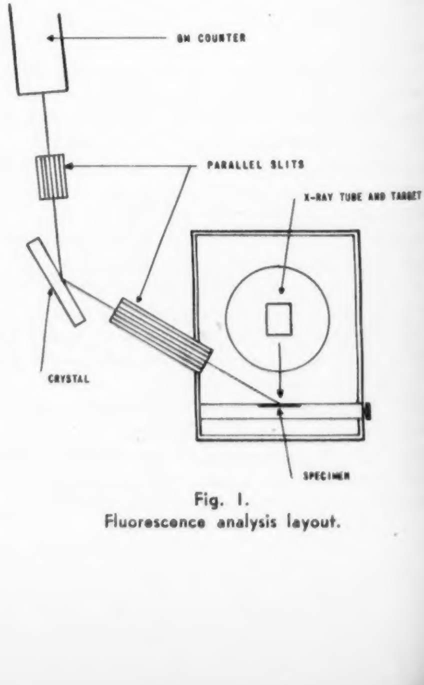

Fig. 1.
Fluorescence analysis layout.

get, to some extent, determines the energy and intensity of the primary radiation. It seems desirable, therefore, to perform the radiation survey under the worst practicable conditions, i.e., maximum scatter as well as maximum x-ray tube voltage and current, because of the large number of possible operating conditions. The condition of maximum scatter was determined from measurements made during the surveys.

Survey Instruments and Dosimetry

THE INSTRUMENTS used for the surveys were: (1) a GM survey meter with a 1.4 mg./cm.[2] mica end window tube (modified AEC model SGM-4D), which was for detection and scanning purposes; (2) a 25 r red bakelite Victoreen thimble chamber and r-meter for small, intense radiation beams; and (3) an ionization chamber survey meter (AEC Model SIC-17C, Juno) with a thin rubber hydrochloride window, for fairly diffuse fields of scattered radiation.

Photographic films were used as detectors of pin-hole leaks. In some cases, the light from a Patterson fluorescent screen was used to define radiation beam dimensions. In this way, reasonable geometry conditions were assured during thimble chamber measurements. Readings were taken under conditions of maximum x-ray tube voltage and current at various accessible points about the diffraction or fluorescence analysis unit.

Corrections up to 1.7 or 1.8 (depending on the x-ray tube potential and the amount of filtration) must be applied to thimble chamber measurements because of the absorption of low voltage x-rays in the chamber wall, in order to obtain an estimate of the exposure rate.[2] Consequently, it is felt that exposure rates determined from 25 r chamber measurements are correct only within about a factor of two.

Use Factor and Shielding

X-RAY PROTECTION design employs one or more of several factors to effect the reduction of exposure rates to permissible levels in occupied areas. These factors involve distance, barrier thickness and actual use time of the x-ray machine in question. Sometimes the occupancy time of radiation areas is also considered. The only factor applicable to the x-ray protection design of diffraction equipment seems to be that involving barrier thickness, the others being ruled out for various reasons.

1. The reduction of personnel exposure by distance, i.e., the inverse square law, is not advisable because the x-ray spectroscopist must work in such close proximity to the unit during its operation, since these machines often require frequent adjustment.

2. The actual use time of this kind of x-ray equipment should be taken as the maximum work day, i.e., not less than eight hours, as specified in the existing A.S.A. Safety Code, Section 3-3.3, since it is often desirable to operate equipment continuously to maintain uniform output.

3. Finally, the actual occupancy time of radiation areas should be considered as the maximum possible for essentially the reasons stated in 1 and 2 above.

The assuming of maximum use and occupancy times does not complicate the protection problem for existing (up to 55 kvp) units because low voltage x-rays are easily attenuated. For example, the half-value layer of 50 kv. x-rays is only a small fraction of a millimeter of aluminum.[2] It seems entirely practical, then, to use enough lead or other material in x-ray tube housings to reduce the direct radiation to negligible exposure rates. Of course, adequate shielding around the x-ray tube and specimen will reduce the possibility of the presence of pencil beams as well as the intense scattered radiation in the vicinity of the specimen and crystal. Levels due to scattered radiation could be further attenuated by permanent shields appropriately placed about the entire unit.

If the upper limit of the potential of x-ray diffraction tubes is extended to something over 100 kv., as contemplated, shielding problems may become more complex, with respect to the changing of specimens while the tube is still energized.

Criteria for Radiation Safety

THE AMERICAN Standards Association "Safety Code for the Industrial Use of X-Rays" describes the safe design and construction of x-ray installations except those used for medical or dental purposes. In this code, two alternative recommendations

are indicated for x-ray diffraction equipment.

1. "Unless the installation is of the Class A type, the required safeguards of 4-2.2, 4-2.3 and 4-2.4 shall be provided."[3] A Class A, Totally Protective Installation, is one having the x-ray machine placed in a permanent enclosure which is inaccessible to personnel by virtue of the use of interlocks. This cannot be complied with by interrupting the tube current without interfering with some types of work. The alternate criteria was used in these surveys.

2. Paragraphs 4-2.2 and 4-2.3 of the Code state, respectively, that the x-ray tube shall be mounted in a totally protective housing, and should have automatically interlocking beam shutters, collimators and shields. "A 'Totally Protective Housing' is one having sufficient protection to reduce the dosage rate of the radiation in any direction (excepting only that of the useful beam) to 12.5 mr./hr. at contact with the tube housing when the x-ray tube is operated at its maximum rated voltage and maximum rated current for continuous operation at that voltage."[3] It should be noted that none of the units surveyed had automatic or interlocked beam collimators. The present maximum permissible exposure rate was taken to be 300 mr./week,[4] rather than 12.5 mr./hr. (500 mr./week) which appears in the Code. It is notable that none of the units tested met even the 12.5 mr./hr. limit in contact. Because of the low penetrating ability of these x-rays, the maximum permissible exposure, i.e., 300 mr. per week, may be relaxed somewhat in recommendations by the NCRP, now in preparation. That is, 300 mr. may refer to the dose to the most sensitive parts of the eyes, blood-forming organs and the gonads. This, in effect will permit a somewhat higher air dose.

Results of Surveys

Examples of radiation levels for the eight x-ray machines which were surveyed are described here.

Unit #1 (50 kv., 50 ma.) is a widely used commercial fluorescence analysis unit located in a mineralogical laboratory. The specimen and holder are placed in the x-ray beam through an opening in the tube-specimen housing. A rather intense x-ray beam was present with the specimen holder removed. The internal shielding flap was too small to cover the opening and the resulting 5/8 inch by 2½ inch beam produced an exposure rate of about 15 r/min. due to secondary radiation near the opening at maximum tube voltage and current. No radiation was detected with the holder in place. Although the unit is not operated with the holder removed, it is necessary during an experiment to change specimens without disturbing the tube voltage or current. The operator's fingers, then, are presumably exposed to fairly intense x-rays for a short time during each change of specimens. This is a needless, potentially dangerous exposure, particularly when one realizes that a thin sheet of practically any material, e.g., 1/8-inch brass, can reduce the exposure rate to reasonable levels. Exposure rates due to stray radiation up to about 1 r/hr. were encountered in the vicinity of the GM tube. No other high levels were detected around the machine.

Unit #2, a non-commercial diffraction assembly, was also located in a mineralogical laboratory. The tube housing is arranged vertically in the center of a bench so that an x-ray beam is available by opening one of the four ports in the tube housing. These ports are located about 4½ feet above the floor. Four hinged lead panels are fastened to the edges of the bench. Neither the port shutters nor the lead barriers are connected to the tube energizing circuit. The exposure rate in the useful beam five centimeters from an open port was about 50 r/min. with the tube operating at 37 kilovolts and 13 milliamperes.

Unit #3, consists of an x-ray tube and a bent crystal monochromator mounted on a bench such that the useful beam is directed horizontally away from occupied areas. An L-shaped steel shield extends from the bench top to a height of about three feet. Pieces of lead sheet cover the x-ray tube and sample during operation. The apparatus is set up before a run by arranging the crystal and sample in the x-ray beam by using a fluorescent screen. Necessary fine adjustments are then made. During the line-up procedure, the tube is operated at 47 kilovolts and five milliamperes. During an experimental run the tube current is raised to 15 ma.

Thimble chamber measurements indi-

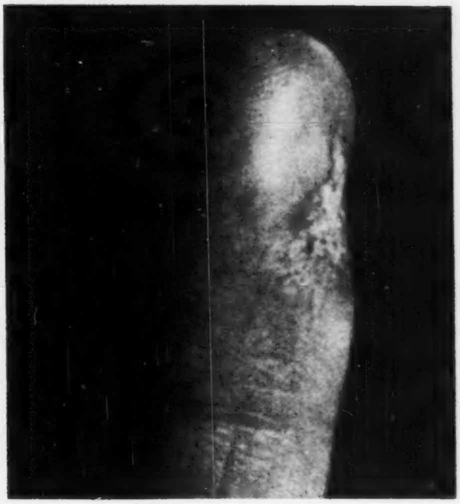

Fig. 2.
Lesion from x-ray burn. Left: seven days after exposure; right: two years after exposure.

cated exposure rates in the useful beam of about 50 r/min. between the tube and specimen holder (about 10 centimeters from the beam slit). After line-up, and with the lead sheets not in place, the Juno indicated exposure rates of several hundred mr./hr. due to scatter a few inches above the slit.

Unit #4, a layout similar to #3, is used in a metallurgical laboratory. The x-ray tube is operated at 47 kilovolts and 15 milliamperes. In addition to high levels like those encountered near Unit #3, an exposure rate of about 20 mr./hr. due to scatter, as indicated by the Juno instrument, was found in front of the bench in the operator's position. Although this level may not be dangerous, it is certainly unnecessarily high when one appreciates the uncertainties in low energy x-ray dosimetry.

Unit #5 (40 Kv, 15 Ma) a commercial (diffraction) model, is used in conjunction with a camera. Stray radiation levels of several hundred mr./hr. were found behind the machine in a rather inaccessible area.

Unit #6 (40 Kv, 15 Ma) also a commercial machine, produced the lowest exposure rates of interest to the health physicist of any unit surveyed. No excessive levels were found though a vertical beam of scatter producing a few mr./hr. was apparent above the tube housing.

Unit #7 is a commercial fluorescence analysis model similar in design and application to Unit #1. The x-ray tube is operated at 45 kv. and 15 ma. The principal objection to this machine is the presence of a rather diffuse radiation field producing about 1 r/hr. at the control panel. Routinely, the operator places a lead glass shield in place between the panel and the x-ray tube, thereby reducing the levels to something below 6.25 mr./hr. (However, it is desirable to rely as little as possible on human discretion in such matters.)

Unit #8 is a commercially available diffraction unit used in powder camera work. A vertically arranged x-ray tube produces horizontal radiation beams through four ports in the tube housing. Since the cameras are generally mounted in front of the ports while the unit is in operation, a rather intense dose can be received by the fingers in a few seconds. The exposure rates in the useful beam due to the approximately ¼-inch diameter beam may be several hundred r/min. a few centimeters from the open port.

Summary and Recommendations

NONE OF THE machines surveyed complies with the ASA Safety Code, although it is believed that the housings of the x-ray tubes can be modified to provide adequate shielding. Since the use of x-ray diffraction

equipment often involves the comparison of an unknown specimen with some standard, a switch to de-energize the x-ray tube while the specimen is replaced with the standard would probably destroy such comparisons. One should, however, consider the use of mechanical interlocks.

In spite of the apparent difficulty of complying strictly with some details of the ASA Safety Code, it is felt that, fundamentally, the Code is practical. However, the x-ray diffraction machine operator should not have to rely on portable shields or coverings to any great extent. One of the machines described above was enclosed in a semi-permanent sheet metal hood at the suggestion of this laboratory. A shutter attached to the tube housing above the specimen holder port reduced the time of potential radiation exposure of the operator's fingers to practically nil. The hood absorbs essentially all of the scatter. With these modifications, it is now felt that this machine has been made as safe to operate as possible. Furthermore, much of the possibility of human error has been removed. Since exposure rates in excess of 6.25 mr./hr. were encountered near all of the machines surveyed, it would seem desirable for users of existing x-ray diffraction equipment to study the necessity and feasibility of supplementary shielding. Furthermore, the recent occurrence of accidents resulting in burns, like the one shown in Fig. 2,[5] leads to the first of the points listed below.

The recommendations are summarized:

1. A more conservative attitude toward radiation exposure should be taken by x-ray spectroscopists.

2. The use of more adequate shielding (especially in the vicinity of the specimen holder) in the manufacture of x-ray diffraction units seems indicated.

3. The users of diffraction equipment should modify existing units to insure compliance with the existing code.

Acknowledgements

THE WRITERS gratefully acknowledge the assistance of H. J. DIGIOVANNI, L. R. SOLON, K. O'BRIEN and S. ROTHENBERG of the AEC Health and Safety Laboratory, as well as that of DR. R. M. WATROUS of the Abbott Laboratories, who supplied the photographs.

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Resolution

THE FOLLOWING resolution was adopted by the Board of Directors of AIHA at the Sixteenth Annual Meeting, April 26, 1955, at Buffalo, New York: "Resolved that the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION express its profound gratitude for the generous and noteworthy contributions of the Mellon Institute through its President, DR. EDWARD R. WEIDLEIN, to the advancement of this Association and the Industrial Hygiene profession during the term of DR. HENRY F. SMYTH, JR., Executive Secretary."

Basic Problems in the Detection of Microbiological Air Pollution

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In recent years an increasing effort has been devoted to the analysis of the atmospheric environment for air-borne particles, the potential hazard of which has come into the foreground with increasing emphasis. Extended efforts have been spent thus on the development of methods which permit the study of the concentration, the origin, and fate of air-borne particles. The ultimate aim is the acquisition of reliable information, not only about the total quantity or general quality, but in many cases about the specific nature of at least some of the particle types in an aerosol. This becomes a necessity in the search for the (generally scarce) microbiological components.

It is the purpose of the following to outline the basic nature of unsolved problems in this field and to point out some solutions.

Three items of information are in general expected from a microbiological aerosol assay, namely: the concentration, the general (or possibly specific) nature, and the viability of the air-borne organisms. Regardless of emphasis, this requires three separate operations, each of which represents a complex of problems in itself, quite independent of the other two, though the results and the basic limitations of each step must be coordinated for arriving at the final information and its margin of confidence.

Basically a sequence of the following operations is involved: (1) Particle separation from the air-dispersed (air-borne) state by producing a concentrate. (2) Reaction of the concentrate with specific biological or biochemical reagents. (3) Evaluation and interpretation of such reactions.

Obviously these steps are related to each other in the following manner: the reliability of both—(2) and (3)—depends upon the successful operation of (1), whereas (3) depends on a suitably chosen procedure for (2). In many instances (3) will be self-evident and come into major importance only when the requirement of the earliest possible detection is of significance.

Presented at the Fifteenth Annual Meeting of the American Industrial Hygiene Association, Chicago, April, 1954.

Separation and Concentration

This step serves the purpose of bringing the particles into a form in which they become accessible to chemical or microbiological analysis. The problems inherent in this procedure are mostly of physical, rather than biological, nature, and as they appear to present the key problem in the entire methodology of aerosol assays, they warrant more detailed discussion.

The fundamental difficulties in tracing organisms from an aerosol is due to *two* basic conditions, one of which is the generally extremely low mass (or volume) ratio between the suspended particles and the suspending air volume, evident from the following consideration:

As the mass of a single bacterial organism is of the order of 10^{-11} to 10^{-12} grams, millions of organisms are required to represent a minimum quantity for microchemical analysis. Hence, if the normal concentration of organisms be assumed to be of the order of one cell/liter (about 30/cu. ft.) (though much larger or much lesser concentrations may occur), it would be necessary to screen 35,000 cu. ft. (1,000 cbm) of air to obtain a few micrograms of microbiological substance.

The magnitude of the physical problem involved may be illustrated by the following example:

Assuming an open area of 10 cm^2 ($\doteq 1\frac{1}{2}$ sq. in.) of an "ideal" screen matrix capa-

ble of quantitative particle retention in the micron and submicron range, and of a flow resistance so small that the air could be forced through it with sonic velocity, the passage of this air volume (1,000 m^3) would still require one hour after which only 1/1000 of the screen area (1 mm^2) would be occupied by micro-organisms. Under practical conditions the actual filter area has either to be 100 to 1,000 times larger and results in a correspondingly still lesser surface concentration, or the time interval of sampling has to be increased by the same factor, which will retard the availability of the required information critically.

The total quantity of concentrate necessary for any one test is drastically decreased if chemical and biochemical assays are replaced by bacteriological culturing methods which, in contradistinction to the former, yield information about the viability of the organisms, restricted in most cases though to rapidly growing forms (bacteria, fungi, etc.).

The second of the aforementioned conditions renders the situation even more unfavorable:

The atmosphere nearly always carries a vastly larger concentration of non-biological particles which can be of almost any chemical and physical nature, so that each airborne organism is in the average surrounded by 10^4 to 10^6 particles of non-living nature. Hence the particle concentrate resulting from the separation process will carry micro-organic matter at concentrations of only 1 to 100 ppm. This condition requires that a microchemical assay of the retained particulate matter on a solid collecting surface, or within a fluid, be based on specific indicators of sufficient sensitivity to react with an extremely small fraction of the concentrate.

Even if this can be realized, the result lacks information about the viability of the organisms contained in the concentrate; hence the latter has to be contacted with a nutrient medium. If a substantial fraction of the particles is of inhibitory nature the formation of the concentrate can already seriously interfere with the viability. The contact with a nutrient, i.e., an aqueous liquid, may enhance this hazard if only a small fraction of the particles have water soluble components (metal salts, oxidants, etc.) which can prevent subsequent growth. Consequently the information gained from such assays may, due to partially or fully impaired viability, not be remotely representative of the microflora of the aerosol prior to the formation of the concentrate. This situation appears to be sufficiently critical to warrant more detailed discussion.

Microbiological aerosols have the peculiar property of permitting the coexistence of a large majority of particles with viable micro-organisms for long periods of time, even if the particles are such that contact or coalescence with them destroys the viability of the organisms.

This somewhat paradoxical situation is caused by the scarcity of collisions among particles of the size classes involved in stable aerosols ($<$ 6 micron), i.e., which, due to their slow settling rate are permanently air-borne in the presence of the normal convection currents. These currents consist of air volumina so much larger than the particle diameter that—no matter how violent the currents the particle will be at rest relative to its immediate environment, so that a significant motion of the particles relative to each other cannot be caused by convection currents in the suspending air mass.

Similarly insignificant in a stable aerosol are attractive forces which may exist initially among certain particles due to opposite electric charges, because they will cause rapid coalescence and thus neutralization of the charges.

The only permanently present mechanism which produces particle contact is the Brownian movement, i.e., the irregular variation of the distance among the individual particles in the size class under consideration, caused by the random collisions with gas molecules. According to Einstein-Smoluchowsky[1] the average (root-mean-square) displacement of a particle diameter (d) in any given direction over a time (t) to be expected from this purely statistical motion is:

$$\triangle x = \left[\frac{2kT}{3\pi\eta} \right]^{1/2} \cdot \left[\frac{t}{d} \right]^{1/2} \cdots\cdots$$

where k, T, η are respectively: Boltzmann's constant, (abs) temperature and the air

viscosity. For a temperature of T = 300° abs (79° F) the average hourly displacement results in:

$$\triangle x = 4.2 \cdot 10^{-4} \cdot (t/d)^{1/2} \ldots\ldots$$

According to this simple relationship a 1 micron (10^{-4} cm) particle, for instance, will experience a lateral displacement of $4.2 \cdot 10^{-2}$ cm, a 5 micron particle only $1.9 \cdot 10^{-2}$ cm in one hour, however not quite 100 times more after one year (ca. 8800 hrs.), namely 3.9 cm and 1.77 cm, respectively.

As a measure of the probability of a collision between two neighbors of equal diameter (d) can be taken the condition where one-half of the average distance (δ) between two particles equals ($\triangle$ x), the average displacement. Since (δ) is inversely proportional to the cube root of the concentration, i.e., $10/n^{1/3}$, where (n) is the number of particles/liter (10^3 cm^3), the above condition is fulfilled if:

$$\triangle x = \tfrac{1}{2}\,\delta = 4.2 \cdot 10^{-4} \cdot (t/d)^{1/2} = 5/n^{1/3}$$

This relation, when solved for (t), gives the number of hours required for an average Brownian displacement of two particles with a diameter (d, in micron) and at a concentration of n/liter to approach each other half-way, as:

$$t = \frac{1.44 \cdot 10^{4} \cdot d}{n^{2/3}} \ldots$$

Fig. 1 represents the variation of (t) with (n) for the sizes (0.1 - 5 micron), significant for aerosols. If the arbitrary condition of ($\triangle$ x = ½ δ) may be taken as a rough measure for a noticeable collision rate, it is evident that isolated bacteria at a concentration (n = 10/liter) reach this state only within a year, that the coexistence with four thousand times the concentration of inhibitory particles of one micron would decrease (t) to one day, and that a further increase of (n) by a factor 10^4 would be necessary to reduce (t) to one minute.

It has to be realized, however, that an appreciable collision frequency will decrease (n) and increase (d), hence (t) will continuously increase. This relationship represents a mechanism which can preserve biological aerosols with values of (n) far from negligible from a health point of view.*

It is thus apparent that the scarcity of interaction among suspended particles must also contribute to a large extent to the preservation of the viability of organisms over extended periods at relatively high concen-

*This is only true for particulate matter and does not refer to inhibitors in molecular dispersion (vapors and gases) since they are subject to rapid transfer by diffusion processes. Neither do these purely kinetic considerations take into account the possibility of a gradual viability decrease due to heat, desiccation, photochemical and even radiological action. This gradual viability loss caused by environmental factors depends to a large extent on the specific sensitivities of the species involved and many other unpredictable factors, none of which are problems directly connected with the assaying problems.

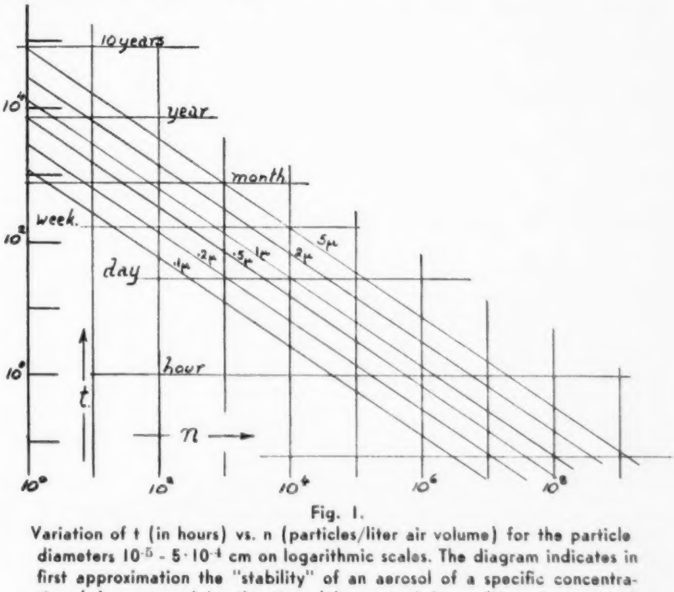

Fig. 1.

Variation of t (in hours) vs. n (particles/liter air volume) for the particle diameters 10^{-5} - $5 \cdot 10^{-4}$ cm on logarithmic scales. The diagram indicates in first approximation the "stability" of an aerosol of a specific concentration (n), measured by the time (t) required for a (Brownian motion) particle displacement equalling one-half of the average distance between neighboring particles. For instance: one week for 5 μ particles at 10,000/liter, one minute for 0.5 μ particles of 100,000,000/liter, etc. It is assumed that collision results in coalescence of the particles and is likely to cause interference with the viability of air-borne microorganisms.

trations, even if the majority of coexisting particles (or droplets) are of inhibitory nature, for their presence will cause little interference.

A concentrated bacterial aerosol should thus reduce itself in a relatively short time to a lesser but rather persistent level, the latter to be the higher the lower the temperature and the smaller the relative concentration of inhibitory particles, provided that coalescence due to irreversible collision among neighbors is the predominant factor.*

The above considerations demonstrate the consequences which any concentration process, required for assaying, must have on an (as such stable) aerosol: the probability of inter-particle reaction is largely increased and can result in a rapid and severe viability reduction of air-borne organisms. Most detection procedures require a concentration factor (n_2/n_1) of at least 10^4 to 10^5 and cause a large increase of collision probability, i.e., a decrease of (t) — since $t_2 = t_1(n_1/n_2)^{2/3}$. For instance: a bacterial aerosol containing inhibitory particles, such that it would lose one-half of its viable organisms in 24 hours, would show the same loss within the first minute after a 2.10^4-fold concentration. Hence the viable counts derived from such a concentrate would result in a serious underestimate of the bacterial content of the aerosol.

It thus becomes obvious that the requirements for maximal preservation on one hand, and for the reliability of information (which depends on the concentration factor) on the other, are mutually contradictory. It is the most important task of any systematic methodology of aerobiological assaying to overcome this basic dilemma.

Feasible procedures will thus have to fulfill the following conditions: (1) the separation and concentrating process should be quantitative and capable of treating large air volumina at high flow rates in order to reduce the sampling period to a minimum of time; and (2) during the process of separation and in the resulting concentrate, the organisms should be afforded maximal protection against coalescence, inter-particle reaction and other adverse physical and chemical conditions so that they are in a state most favorable for rapid and uninhibited growth development.

Almost all assay methods available at present require two steps in order to approach both conditions satisfactorily, although for specific purposes certain single-step procedures have shown obvious merit. They are limited, however, in fulfilling both conditions simultaneously.

One of the simplest processes consists in impinging the air stream (through a slit or circular orifice) onto a semi-liquid nutrient (agar or gelatin) surface and effecting a relative movement between orifice and surface, which aims at avoiding an undue particle accumulation on the surface. Various designs following this principle exist and have given in many cases excellent results. Common to them, however, is the limitation of the total air volume sampled and a relatively low sampling rate (5 to 10 liters/-min.), which can affect the over-all confidence adversely.

Another much simpler one-step procedure is the direct screening of the air through a suitable type of molecular filter membrane (MF), as described by the author.[2] The MF's act like screens of an extremely fine mesh (about 10^7 pore openings/cm^2) with a high flow permeability (about 1 to 3 liters/cm^2/min./cm Hg differential pressure). The separation of solid particles down to and below 10^{-5} cm diameter from aerosols appears to be complete. The retained (solid) matter is concentrated on the MF surface where it is predominantly held by electrostatic forces generated by the air

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*Coalescence, however, results not only in a decrease of (n) but also in a gradual elimination of total suspended matter, when the particles grow to such sizes that dropping-out occurs. Applying Stoke's law as a fair approximation for the settling rate, one single microorganism should drop a foot in completely tranquil air in about 3½ hours. If however the same particle has grown by repeated collision with others to 10 times that size, it will drop over the same distance in 20 minutes. From this it is evident that the classical procedure of exposing sterile nutrient agar plates for a certain length of time to the air results in a purely arbitrary impact by micro-organisms: if one assumes the air column above the standard dish ($d = 9$ cm) to be perfectly tranquil, and all organisms suspended as single cells, the time necessary for *all* organisms to drop from a column representing one cubic foot over an area equal to that of the dish would be about 130 hours. The fact that an air volume of this magnitude can never be kept tranquil, and is continuously exposed to irregular drifts, can change the settling rate or even obliterate it completely for particles of this size class, whereas agglomerated particles or micro-organims attached to substantially larger particles with a higher settling rate will reach the plate very much faster; therefore it appears extremely difficult to derive from such a plate count even a rough estimate of organisms in the surrounding aerosol.

flow through the dielectric matrix of the MF membrane. The sampling rates obtainable are high, about 100 liters/min. at ½ atm. (15 inches Hg) pressure differential over a (standard) circular filter area of about 10 cm^2—while the concentration factor (n_2/n_1) is almost infinite due to the reduction of the aerosol to a two-dimensional particle layer. Within this layer, however, conditions can occur which are conducive to coalescence and interaction among the particles of the deposit, especially upon prolonged sampling periods.

The direct MF screening of microbiological aerosols can thus seriously interfere with the viability in the presence of inhibitory matter,[3] while the recovery can be excellent when such matter is minimal or the screening period is brief. Comparative studies with other sampling methods have shown a large dependence of the viable recovery upon the humidity in the sense that the recovery is very good for high (RH$>$ 70%) and low for medium and low humidities, suggesting a "drying-out" process of the cell deposit on the MF surface. Similarly, the viable recovery appears to decrease for low humidity with the exposure of the particle to the air stream passing the MF,* i.e., with the sampling period.[4]

Elimination of this phenomenon has to be given serious consideration when selecting a concentration process, i.e., either direct exposure of the deposit to the air flow must be minimized, or the concentrate should be formed directly within a liquid from which the particles can then be transferred to a nutrient medium. Evidently such processes require two steps, of which the first causes a rapid concentration within a small volume of liquid, or within a porous water-soluble solid gel structure, while the second step effects the conversion of the liquid (possibly after further concentration) into a form suitable for culturing the organisms.

The *physical* advantage of the first step is the drastic reduction of the Brownian motion due to the increased viscosity of the liquid vs. a gaseous medium, which can decrease the probability of particle interaction several hundred times.

The *chemical* advantage of the conversion to a hydrosol is the possibility of neutralizing the inhibitory effects caused by the soluble constituents of the coexisting particles and by "shielding" the microorganisms with protective colloids against inhibitory coalescence. Apparently for this reason the use of dilute (0.1 to 0.5%) gelatin solutions as impinger fluids has proved advantageous with regard to increased viable recovery, with further improvement by the addition of buffering agents for the neutralization of acid or alkali particles, the addition of reducing agents, such as thiosulfates, thioglycolates, etc., as protection against air-borne oxidants. The composition of the fluid can probably be adjusted to the locally prevailing conditions in each case.

Available experience has indicated that suitably designed liquid impingers are capable of an almost quantitative retention of airborne matter and are also capable of obtaining relatively high concentrates. The inherent practical difficulty of this type of concentration, however, is the limited ratio between flow rate of air and volume of liquid, the improvement of which can involve a sacrifice of retention efficiency. Present design attains a maximal sampling rate of about 100 liter/liter of fluid/min., i.e., the particles contained in 1,000 liters of air (1 cbm) can be concentrated in one liter of impingement fluid within 10 minutes, equivalent to a concentrating speed of 100/min.

A very promising variant of the separation and concentration process has recently been developed by Mitchell et al[5] who use a solid, but water soluble, three-dimensional filter matrix in the form of a dry gelatin foam cake through which the aerosol is filtered and which is subsequently dissolved in a sterile saline solution. The complication of this additional step is off-set with the advantage of being able to sample in a temperature range where the impinger fluid

*It appears logical on first sight to assume that the surface of a particle which has been airborne for a certain length of time has reached complete moisture equilibrium with its atmospheric environment. If this particle is then intercepted by and held on a screen-like surface, the "air shear" so produced at the surface of the "resting" particle should not alter its moisture content. The experience that such "air shear" conditions can decrease the viability very seriously suggests conditions at the cell surface which delay or even prevent the moisture loss by diffusion into its gaseous environment while the latter is at rest with regard to the cell surface. This protective mechanism appears to fail in the presence of an air flow relative to the cell surface.

would freeze. The consistently higher viable recovery, compared with the direct MF filtration, indicates the significance of the contact of the retained organism with an agent capable of acting as a protective colloid, such as gelatin; and furthermore the importance of avoiding the formation of the deposit on a surface directly exposed to the air flow.

A basically different approach to the concentration problem, designed by the author, though still in the exploratory stage, promises to combine a significantly increased concentration rate with nearly complete protection against interparticle reaction. It consists of the rapid "deep freezing" of the air stream by heat exchange with a refrigerant gas, such as CO_2 expanding in a vortex, and the subsequent separation of the resulting ice fog by the centrifugal action of a vortex (cyclone). The result is a "size spectrum," i.e., a frozen surface deposit wherein the particles are roughly classified with regard to their size (and mass), so that a selection (or elimination) of certain particle sizes prior to further treatment is possible. The process is likely to minimize particle interaction until the frozen concentrate can be thawed in a protective fluid, from which it may be subsequently separated by MF filtration. The additional complications may be offset by the possibility of processing much larger air masses for sampling and by improved viability preservation.

The Culturing Process

THE PROCESS of forming the concentrate of particles in a protective medium has to be followed by a second step which effects intimate contact of the suspended matter with a nutrient medium without or with prior separation from the suspending fluid.

This procedure lends itself to a number of variations for all of which it is desirable that the chemical neutralization of the soluble components in the aerosol and the colloidal protection of the micro-organism has taken place *prior* to the contact with the nutrient, so that the soluble matter cannot affect it and cause inhibition of the subsequent growth development. The application of methods developed for water bacteriology can well be adapted, i.e., serial broth cultures aided by plating on specific media, because these techniques involve large dilution factors. The results suffer in general, however, from large statistical uncertainty unless numerous parallel sample portions are employed.[6]

This disadvantage can be avoided by filtering the concentrate through molecular filter membranes (MF's) (HA type) as they permit at relatively high flow rates complete bacterial retention and subsequently "in situ" culturing of the retained material on the surface of the MF.[9] In this manner a separation of the suspended matter from the suspending fluid and an elimination of its action upon the medium is effected without involving much delay. The filtration of the concentrate proceeds at a rate of about 1 cm/sec., so that a liter of concentrate passes an MF area of 10 cm^2 in two to three minutes (if care was taken that the impinger fluid was prefiltered to avoid the presence of suspended matter other than that retained from the aerosol). The (volume/surface) concentration rate of this step is thus of the order of 50/min., which means for the above example that each cm^2 of the MF surface will carry a concentrate of particles originally suspended in 100 liters of aerosol.

The entire concentration process, i.e., both steps combined, will involve 10 to 15 min. for the separation of the suspended particles of 1,000 liters air on 10 cm^2 MF area. Comparison of this value with direct (one-step) filtration through an MF results in flow rates of about 5 liters/cm^2/-min, i.e., in approximately the same concentration rate as in the above two-step process.

The use of the MF technique for the secondary concentration process and subsequent matrix for the colony development appears to have very substantial merit, not only because of a rapid concentration with minimal impairment of viability,[4,7,8] but also because of rendering dilution and plating operations unnecessary and thus minimizing the requirements for sterile glassware, etc., and therefore lends itself very well to application in the field.

The culturing technique consists simply of contacting the MF side opposing the retained layer with a sterile paper pad which is impregnated with the nutrient prior to use, or is prefabricated with a dehydrated

nutrient, so that only moistening prior to use is necessary.[10] Subsequent incubation yields in general reliable counts in 12 to 24 hours, though certain organisms (fungi, mycobacilli, etc.) may require longer incubation periods. Methods for applying simultaneously a variety of nutrients facilitating a general survey of the nature of the air-borne flora are possible with this method as well.

With regard to further detail, reference to the extended literature[9] on the MF application for water bacteriology is made.

While the nutrient types developed for water bacteriology with the MF are well applicable to the air-borne flora, it is a common experience to encounter numerous motile organisms (spreaders) which obscure or antagonize on the MF surface more delicate and slower growing species. In many instances this requires the addition of specific inhibitors to the nutrient (or better, already to the impinger fluid).

The use of the MF technique can be handicapped when there exists a large uncertainty about the particle concentration in the initial aerosol. If the concentration is too large the MF may be clogged before completion of the filtration, or, though no clogging occurs, the number of organisms may be too large to be countable.

This difficulty can be lessened by applying the principle of concentrometric filtration,[11] which results in a graded (wedge-like) particle deposit on the MF surface. Since the density variation of the deposit is mathematically defined, a region of the MF surface can be selected where the colony density permits for an accurate determination. As the volume fraction of the concentrate which has passed this region is known, a direct indication of the original concentration in the aerosol is obtained over a wide range.

Interpretation of Results

THE INTERPRETATION of the resulting cultures yields data about the probable number of organisms in the air sample. According to the well-known laws of statistics, the "confidence" will increase approximately in logarithmic proportion to the product of the sample volume and the concentration of the organisms.

It appears that with present available methods the concentration rate cannot be substantially increased, so that assuming complete preservation of viability, the lower limit of bacterial detection for an MF-culturing area of 10 cm^2, or the equivalent plate area, would lie at about 3 org/100 liters (1 org/cu. ft.) for each minute of sampling operation (for a statistical confidence of 95%); this lower limit increases in direct proportion with the area and/or sampling time.

It appears doubtful, however, whether the same concept of statistical confidence, assumed in water bacteriology, can be applied to aerosols, first, because the degree of uniformity of an aerosol is unknown in most cases and therefore the smallest volume of a truly representative sample.* Second, it can be safely assumed that the isolation of the bacterial flora from water does not interfere seriously with its viability, whereas this is obviously a serious problem for air-borne organisms; hence it follows that the interpretation of the results of an aerosol assay resulting even from parallel tests with a variety of techniques should not take the lack of growth as a proof for the absence of viable organisms in the air-borne state.

Summary

THE PROBLEMS involved in the microbiological assay of aerosols are in part due to the generally low concentration of microorganisms and their coexistence with large numbers of particles of potentially inhibitory nature—and in part due to the relative stability of such aerosols at low concentrations and their instability at high concentrations which can cause misleading losses of viability in the sampling process.

The principal considerations and limitations of such assaying procedures are discussed, as far as they can preserve viability and at the same time avoid reduction of sampling rate. Presently available methods

*In this respect, a comparison with a sanitary water standard may be of interest: these standards[6] allow not more than a statistical average of 11 organisms/liter, a concentration which requires a set of test portions amounting to 100 to 300 cm^3 for 67 - 95% confidence. If similar standards would exist for the individual air intake, samples of 1,000 to 3,000 liters would be required, even if the same degree of uniformity of bacterial distribution could be assumed, as the average adult consumes at least 10^4 times as great a volume of air as the consumed volume of drinking water.

are estimated to attain a sensitivity limit of the order of 1 org/cu. ft. of air per minute of sampling. A specific procedure is discussed which employs an initial conversion of the air-borne matter into a liquid suspension in the presence of protective colloids by an impingement process, followed by further concentration and subsequent nutrition on molecular filter membranes.

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Department of One-Paragraph Reports

TO THE EDITOR: I believe many industrial physicians and hygienists will agree that the toxic effects of many new chemicals, as well as some unusual toxic effects of old chemicals, often escape publication in the literature because the observation of such effects occurs as a single isolated instance. The occurrence is unplanned and unwanted, is considered an undesirable accident, and measures are usually taken to be sure it is never repeated. The attending physician has to act on the spur of the moment, and does not have time to make the accurate measurements and observations that would make the case respectably "scientific." All he would have to report, if he did report, could be said in one paragraph, and for some reason we are all bashful about putting our names to such a minute opus. The information, shorn of scholarly clothing and bibliographic ornament, and naked in its incompleteness, could still be useful to others. I suggest, therefore, that the *AIHA Quarterly* have a column or page entitled "Department of One-Paragraph Reports," to which such material might be sent. A number of industrial physicians have commented favorably on this idea. How about it? (See page 140 for a Report of the kind suggested.) —R. W.

Motor-Driven Syringes
FOR MICRO-METERING OF GASES

BERNARD E. SALTZMAN, U.S. Department of Health, Education, and Welfare
Public Health Service, Occupational Health Field Headquarters, Cincinnati

THE ACCURATE preparation of known concentrations of various gases and vapors in air is a matter of considerable importance in industrial hygiene work. Known concentrations are required for the calibration of instruments, as well as for testing sampling efficiencies and the adequacy of analytical methods. Whereas a variety of methods have been used for this purpose, some are not accurate when used with appreciable flows of air; others are incapable of handling reactive or corrosive materials.

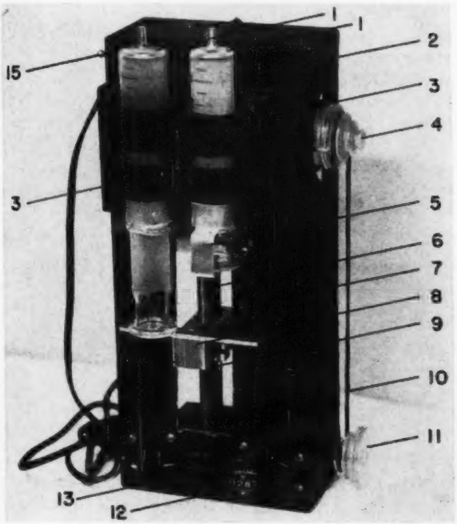

Fig. 1.
Front view of apparatus.

An all-glass 50 ml. hypodermic syringe with a motor-driven plunger has been found to be capable of micro-metering gas with a precision of a few parts per thousand, and has given quite satisfactory performance with corrosive material. The leakage of the syringe has been found to be negligible under the low pressure difference used in ordinary operation.

Front and back views of the syringe device are given in Figs. 1 and 2. The apparatus is used in a vertical position so that the syringe plungers rest upon the motor-driven slide by gravity. If only one syringe is to be used, the clip is placed on the other syringe to hold the plunger. The rate of injection of the gas mixture is controlled by moving the belt on the stepped pulleys of the synchronous phonograph motor drive. Fifty ml. of the standardized gas mixture can be injected in 7½, 16, 28, or 58 minutes. The amount injected is determined by counter readings on the motor drive and micrometer measurements of the syringe plunger diameters (approximately 7000 on the counter

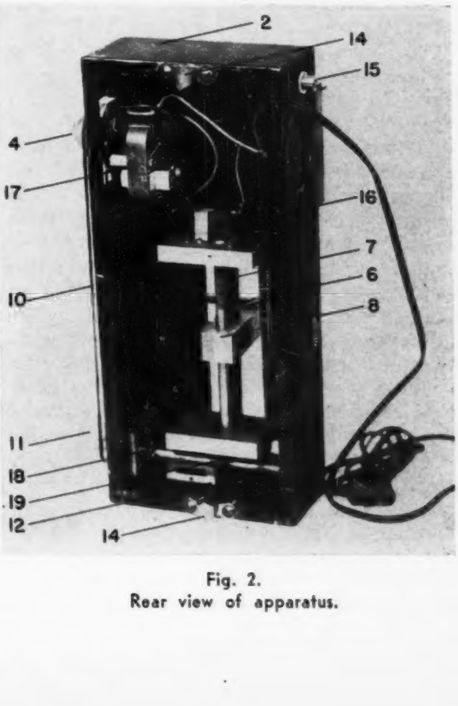

Fig. 2.
Rear view of apparatus.

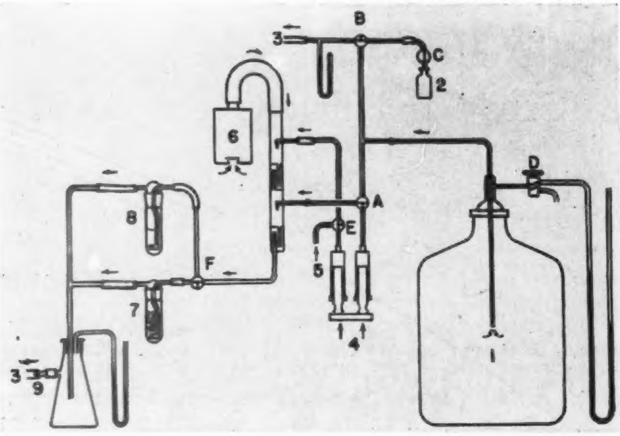

Fig. 3.
Application to preparation of nitrogen dioxide samples: (1) 46 liter carboy containing 20 ppm nitrogen dioxide-air mixture; (2) 60 ml. evacuated sample bottle for standardizing contents of carboy; (3) vacuum connection to aspirator in hood; (4) motor-driven 50 ml. glass syringes; (5) connection for second gas used for testing interferences; (6) universal gas mask cannister for purifying air stream; (7) sampling device; (8) by-pass device of same resistance as (7), used while apparatus is being flushed; (9) critical orifice used to control air stream flow.

= 50 ml.). A limit switch stops the motor when the syringes are empty and thus prevents their accidental breakage.

The apparatus is constructed on a 6" x 14" x 3" radio chassis (2). Switch (15) controls the power to phonograph motor (17). The 7/32" shaft of this motor, turning at 3600 rpm drives a 2" idler wheel, which was originally intended to drive the rim of the phonograph turntable. A lucite pulley (4) is screwed directly to this idler wheel. Four steps are provided from ½" to 1¾". A continuous rubber band (10) cut from an automobile inner tube, transmits the power to a similar pulley (11), the shaft of which turns in ¼" radial thrust ball bearings (Boston Gear Works #501). A sprocket connection (18) (Boston Gear Works CBA 10) drives counter (12), which should have at least four-digit capacity. A steel worm (19) (Boston Gear Works LSH, 48 pitch single thread) mounted on the middle of the shaft turns the 2", 100-tooth bronze worm gear (13) (Boston Gear Works G-1023). The shaft of this gear, turning in ¼" ball bearings of the same type as above, is threaded 24 to the inch (7) to drive the slide (8). By means of lever (9) the split nut in the slide can be opened against spring pressure to move the slide manually. The rear of the slide is guided by the greased smooth rod (6). The limit switch (16) (pin-type light-pressure micro-switch), normally closed, opens the power circuit when the slide contacts it at the end of its travel. The syringes (1) are held in a grooved wooden cradle by rubber straps (3) cut from an inner tube. When only one syringe is to be used, clip (5) holds the other one in the closed position. The entire apparatus is clamped to a rod or ringstand by means of straps (14). The cost of the parts is not high, and the construction is relatively simple.

As an example of the application of the motor-driven syringes, the system used for the preparation of standard nitrogen dioxide samples in air, in the range of a few tenths of a part per million, is shown in Fig. 3.

This apparatus was used for testing sampling efficiency and for the development of a new analytical method. The source of the nitrogen dioxide was a standardized air-mixture contained in a 46-liter carboy and available through an all-glass system of 1 mm. bore tubing and ground joints lightly greased with silicone grease. The gaseous composition was found to remain remarkably constant. During four months, after more than 100 runs, it only decreased from an initial value of 20 ppm to 15 ppm. Known low concentrations of nitrogen dioxide were prepared by injecting the contents with the syringes into an air stream passing through the sampling device.

Acknowledgment

THE author is indebted to OSCAR C. MARSH for the machine shop work on the apparatus and for valuable assistance with the design.

Collection Efficiency of Air Cleaning and Air Sampling Filter Media

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THE EVALUATION of an air cleaning and air sampling program requires an accurate knowledge of the collection efficiency of the filter media used.[1] The efficiencies of filter media have been determined by several investigators on a mass basis and using liquid particles.[2,3] The use of collection efficiencies determined with liquid particles to establish the efficiency of the filter media when solid particles are collected has been opened to criticism.[3] In general, the filter media at the Knolls Atomic Power Laboratory are used to collect solid particles or contaminated atmospheric dust particles.[4] It was, therefore, necessary to know the filter collection efficiencies for solid particles and atmospheric dust. Since the retention of particles in the upper respiratory tract and the alveolar[5] as well as the collection efficiency of the filter media is dependent on particle size, there was a definite need to know the filter collection efficiency as a function of particle size.

The Whatman-40 and Hollingsworth and Vose-70, air sampling filter papers and the Chemical Corps-6, an air cleaning filter medium, are used at the Knolls Atomic Power Laboratory. The collection efficiencies of these filter media were determined in the particle size range of 0.005 to 2.1 microns in the face velocity range of 0.5 to 250 cm./sec. The Whatman-41, the AEC-1 and MSA-1106-B Fiberglass filter media used at other AEC installations were studied for comparative purposes in the same particle size and face velocity ranges.[6]

Presented at the Fifteenth Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, Chicago, April 29, 1954.

Knolls Atomic Power Laboratory is operated by the General Electric Company for the U.S. Atomic Energy Commission.

Experimental Procedure

TEST AEROSOL: Duraluminum was used as the test aerosol for the light microscope filter efficiency studies. A duraluminum rod was held at constant pressure against a revolving steel wire brush to produce a solid particulate material with a density of 2.7 gm./cm^3. An impaction plate was used to capture the particles above five microns, thereby producing a test aerosol with a satisfactory distribution of particles in the range of approximately 0.1 to 2.1 microns.

The collection efficiency of several air cleaning and air sampling filter media were studied at face velocities of 0.5 to 250 cm./sec. The Millipore Filters used to test the filter media were analyzed under both the light and the electron microscope. Collection efficiency was expressed as a function of particle size and face velocity.

Solid duraluminum particles with a density of 2.7 gm./cm.^{3} were used as the test material to determine the collection efficiency of the Whatman-40 and 41, the Hollingsworth and Vose H-70, the AEC-1, the CC-6, and the MSA-1106-B filter media. The collection efficiency of these filter media was investigated for particles in the size range of 0.18 to 2.1 microns by a light microscope analysis.

Atmospheric dust was used as the test material for the efficiency studies in the particle size range from 0.005 to 0.2 micron. A silica replication of Millipore Filter medium was made to prepare the test air samples for analyses under the electron microscope. This replication method minimizes the opportunity of forming agglomerates during the process of preparing the Millipore Filters for an electron microscope analysis.

General atmospheric dust, as found in the Health Physics Development Laboratory atmosphere, was used as the test aerosol for the electron microscope filter efficiency studies. The general atmospheric dust had a standard deviation of 3.05 and a geometric mean size of 0.028 micron, as determined with the electron microscope. The use of general atmospheric dust as the test aerosol duplicates satisfactorily the field conditions normally found at KAPL. Since the density of duraluminum and general atmospheric dust are so nearly the same, filter efficiency data from the light microscope and electron microscope studies were combined.

Since general atmospheric dust particles, due to their varying shapes, are rather difficult to size count, MgO dust was investigated. The MgO particles were consistently cubical in shape, but they tended to floculate in chains and did not present a representative distribution of the particles in the air. Therefore, all of the electron microscope filter efficiency data were obtained using general atmospheric dust as the test aerosol.

SAMPLE COLLECTION: The arrangement used to expose the test filters to the aerosol is illustrated in Fig. 1. When using the duraluminum aerosol, room air is cleaned by a high efficiency filter at (B) before it enters the generation chamber (A). When using general atmospheric dust as the test aerosol, the filter at (B) is by-passed and the duraluminum generator at (A) is left inactivated. At (C) an impaction plate takes out dust exceeding five microns in diameter. The test aerosol passes through the duct (D) and smoothing vanes (G) to

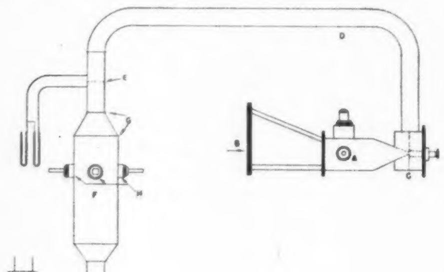

Fig. 1.
Schematic diagram of test unit.

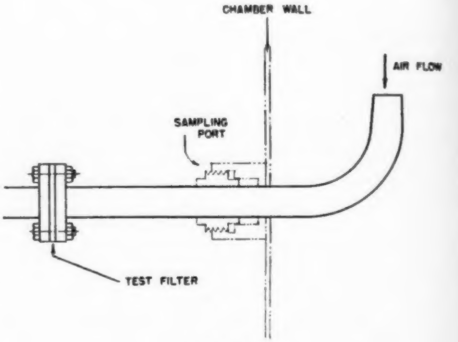

Fig. 2.
Isokinetic sampling head.

the aerosol chamber (F). Sampling ports (H) are located at 90° intervals around the circumference of the aerosol chamber.

Isokinetic sampling tubes, as shown in Fig. 2, pass through two of the ports in the aerosol chamber. The filter to be tested is held between flanges in one of the isokinetic sampling tubes. The exhaust end of the sampling tube holding the test filter is connected in series with a type HA Millipore Filter. Another Millipore Filter, mounted at the second port, samples the aerosol exposed to the test filter. Both Millipore Filters sample at the same flow rate, so that a direct comparison of the aerosol collections on the two filters yields an efficiency evaluation for the test filter. The efficiency is expressed as a function of face velocity of the air stream passing through the test filter with particle size as a parameter. The face velocity is varied by altering the cross sectional areas of the test filter while maintaining a constant flow rate. The experimental apparatus is shown in Fig. 3.

The holder for the Millipore Filters is illustrated in telescopic view in Fig. 4. When the unit is partially assembled and ready for loading with a Millipore Filter, the filter support (B) is in the housing (G) with the spring relaxed. After placing the filter on the support, the hollow plunger (A) is pressed down on the filter, pushing the filter, its support, and the plunger into the unit housing. A locking pin holds the plunger in this position and the compressed spring presses the filter support and filter against the plunger to form a leak-tight filter holder.

SAMPLE ANALYSIS: The filter efficiency evaluation was accomplished in two stages, (1) for 0.2 to 2.1 micron particles with the light microscope, and (2) for 0.005 to one micron particles with the electron microscope.

In the light microscope phase of the evaluation, the Millipore Filter is impregnated with microscope immersion oil, which renders the filter transparent. A cover glass is placed over the sample and a standard size count is made. A comparison of the upstream and downstream size counts, corrected for scanning area, then yields the particle collection efficiency of the test filter for particles in the light microscope size range.

The light microscope and automatic stage moving mechanism are shown in Fig. 5. The automatic stage moving mechanism, a synchronous clock motor driving through a Metron variable ratio speed changer, reduces eye strain and considerably increases the efficiency of size counting. The automatic stage drive, used concurrently with a semi-automatic counting system reduces the counting time by at least 50%. The counting system, shown in Fig. 6, is merely a series of six electrical registers actuated by depressing a micro switch with the appropriate key, selected as a result of measuring a particle of a prescribed size under the microscope.

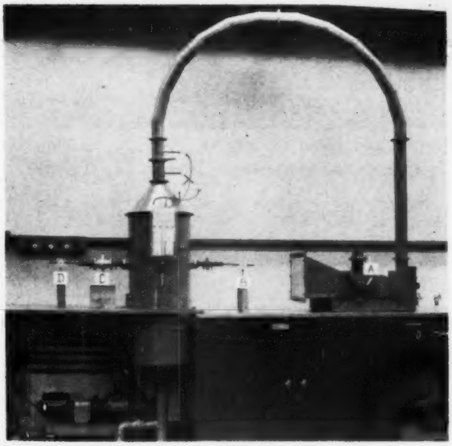

Fig. 3.
Dust generator and collection chamber.

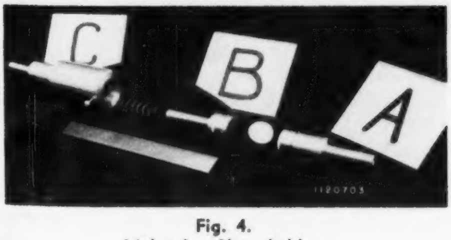

Fig. 4.
Molecular filter holder.

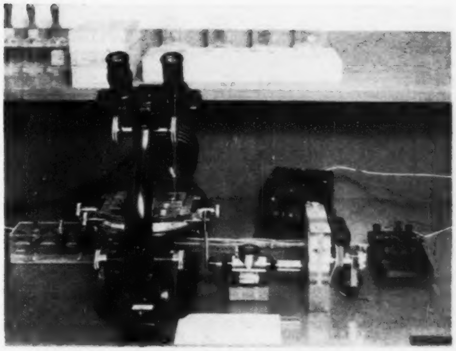

Fig. 5.
Light microscope stage moving mechanism.

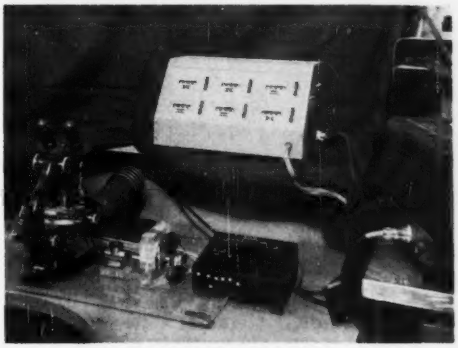

Fig. 6.
Semi-automatic particle counting mechanism.

In the electron microscope phase of the efficiency evaluation, the Millipore Filter was treated for a size analysis by two different methods, the Silica Replication[7] and the Formvar Technique.[8]

In the Silica Replication Method, the silica film is deposited on the filter by the rapid evaporation in a 0.1 micron vacuum of approximately 1.3 mg. of silicon dioxide or silicon monoxide from a coil tungsten filament. The filter is placed 10 cm. from the

filament and normal to it. The evaporation must be done rather rapidly to avoid damaging the filter by the heat from the filament. Small pieces of the coated filter are then placed on microscope specimen screens, with the silica film in contact with the screen. The microscope specimen screen is placed on a 100 mesh screen forming a low table in a depression of a spot plate. Acetone is placed under the table from a capillary pipette until the level of the liquid reaches the top of the table but does not cover the specimen screen holding the sample. Capillary action carries the acetone up to the filter. The level of acetone is maintained until the filter is dissolved.

In the Formvar Technique, the filter is placed on a formvar coated electron microscope specimen screen. The filter is dissolved by acetone in contact with the filter paper and the specimen screen. Capillary action in this method also carries the acetone up to the filter paper. The particulate material from the sample is deposited on the formvar as the filter dissolves.

A brief comparison of the two methods indicates some advantages and disadvantages for both methods. The Formvar Technique permits the presentation of the particles collected in a clear surface background while the Silica Replication Method presents an objectionable replication of the Millipore Filter surface. Size counting using the Silica Replication Method is more difficult but not impossible as the data indicate. The silica method, however, is preferred at KAPL since there is less chance of disturbing the original particulate collection in the filter medium. The silica replication tends to minimize the production or destruction of aggregates or floculations in the medium.

Electron micrographs are made from the silica replicas after selecting fields representative of the particle size distribution and concentration. Size counts are made from the electron micrographs. The data are analyzed in the same manner that the light microscope data were treated to establish the particle collection efficiency in the electron microscope size range.

It was necessary to determine the particulate background on unexposed Millipore Filter papers prior to determining the significance of submicroscopic particles shown on the electron micrographs of Millipore Filters exposed to the atmosphere. An electron micrograph of an unexposed or control Millipore Filter is shown in Fig. 7. The surface of the filter paper is shown in replica form with a magnification of 15,000.

An electron micrograph of a Millipore Filter paper exposed to atmospheric test dust is shown in Fig. 8. The magnification is 20,000 and particles down to 0.005 micron

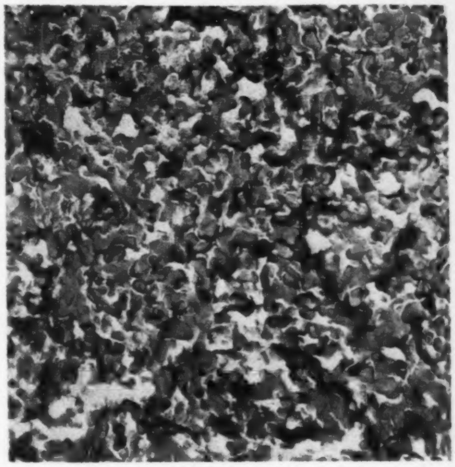

Fig. 7.
Control millipore filter electron micrograph.

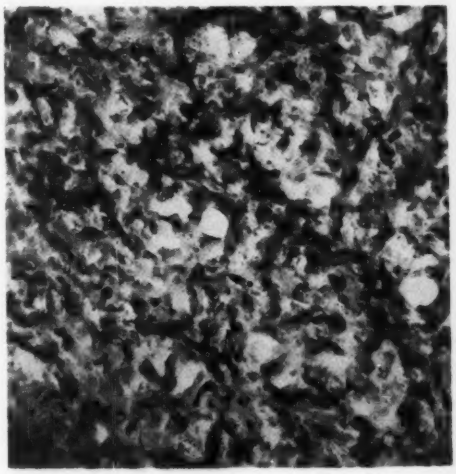

Fig. 8.
Exposed millipore filter electron micrograph high surface structure impedance to size counting.

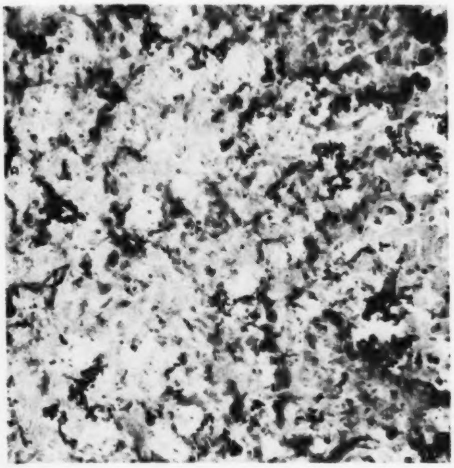

Fig. 9.
Exposed millipore filter electron micrograph low surface structure impedance to size counting.

are readily discernible even with the obstructing background. Some of this background, however, can be eliminated as shown in Fig. 9. There appears, however, to be some variation in the surface structure of the Millipore Filters which permits the reduction of the obstructing background rather than a variation in the technique applied in the preparation of the electron micrograph.

Experimental Results

PARTICLE COLLECTION efficiency, expressed in the generally accepted percent penetration, was determined as a function of face velocity with particle size as a parameter, for Whatman-40, Whatman-41, Chemical Corps-6, Hollingsworth and Vose-70, AEC-1, and MSA-1106-B Fiberglass filter papers. Each paper was tested throughout the face velocity range of 0.5 to 250 cm./sec. in the light microscope size range, 0.2 to approximately 2 microns. The efficiency curves for each paper are given in the following six figures.

The results from the Whatman-40 filter paper tests are shown in Fig. 10. Maximum penetration, or minimum efficiency, clearly occurs at a face velocity of 10 cm./sec. for the entire size range. The optimum operating conditions appear at 40, 100, 150, and 200 cm./sec. face velocities.

The data for Whatman-41 paper tests are shown in Fig. 11. The worst operating conditions appear at 2 cm./sec. face velocity, and the optimum conditions are found in the range of 20 to 100 cm./sec. The Whatman-41 paper has the unique characteristic of a reduced spread of efficiency with size at the optimum operating range of face velocities. Since the Whatman-41 paper is relatively inefficient, the spread is not as compressed on a percentage basis, as the spread for the higher efficiency papers such as Chemical Corps-6.

The efficiency curves for Hollingsworth and Vose H-70 paper are shown in Fig. 12. The optimum operating conditions were observed at 80 cm./sec. with a considerably compressed spread of efficiency as a function of particle size. Minimum efficiency was observed at face velocities of 1, 10, and 100 cm./sec.

The efficiency curves for Chemical Corps-6 paper indicate that this paper is

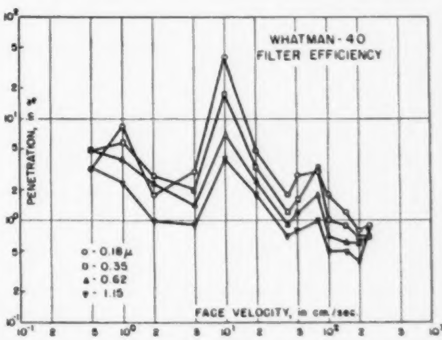

Fig. 10.

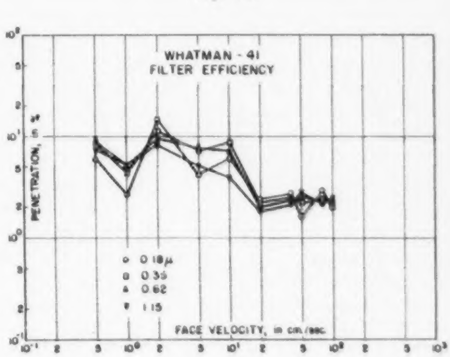

Fig. 11.

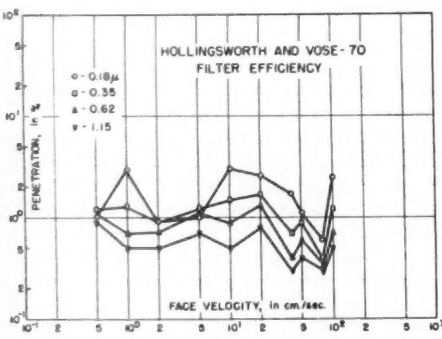

Fig. 12.

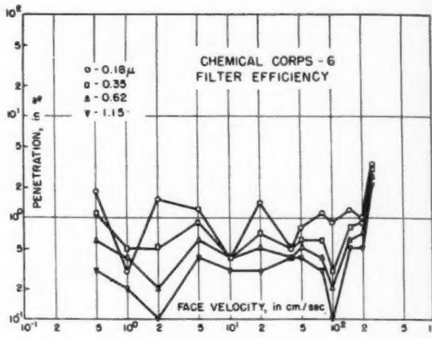

Fig. 13.

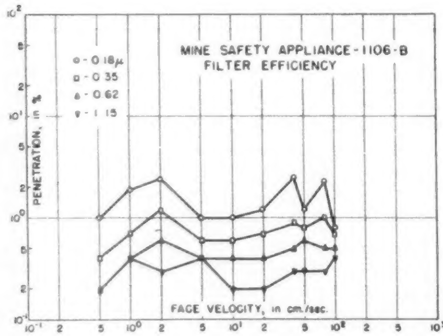

Fig. 14.

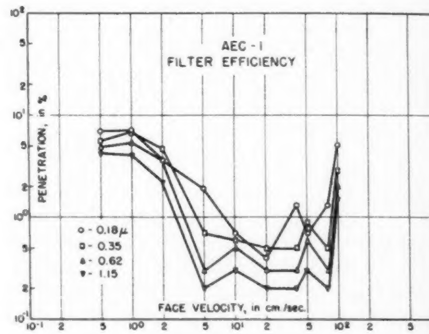

Fig. 15.

the most over-all efficient paper of the group tested. Optimum operating conditions prevail at 10 and 40 cm./sec. face velocities with the poorest operating conditions at 0.5, 2, 5, 20, 80 and 100 cm./sec. face velocities, as shown in Fig. 13.

On a relative basis the poor conditions for CC-6 paper compare with some of the better conditions for the other papers.

The MSA-1106-B glass filter paper, shown in Fig. 14, compares favorably with the CC-6 paper with the exception of spread. The optimum operating conditions prevail at face velocities of 1, 5 and 100 cm./sec.

The results for uncoated AEC-1 filter paper are presented in Fig. 15. Minimum operating conditions appear at 0.5 and 100 cm./sec. face velocities, and the optimum operating conditions appear at 10, 20 and 50 cm./sec. face velocities.

A summary of the maximum and minimum percent penetration for each filter paper tested as a function of face velocity is presented in Table I. The lower face velocities generally permit the maximum amount of particulate penetration through the filters, and the higher face velocities generally prevail during highest collection efficiency.

TABLE I.
PERCENT PENETRATION OF 0.18 MICRON PARTICLES

Type Filter	Maximum		Minimum	
	Percent Penetration	Face Velocity, in cm./sec.	Percent Penetration	Face Velocity, in cm./sec.
W-40	40.4	10	0.8	200
W-41	14.8	2	1.6	50
CC-6	3.3	250	0.3	1
H-70	3.0	10	0.6	80
AEC-1	7.1	1	0.4	20
MSA-1106-B	2.5	40	0.8	100

The particle collection efficiency of Whatman-40 filter paper at a face velocity of 40 cm./sec. was determined with both the light and electron microscope. The results are given graphically in Fig. 16. The particle size range detected with the electron mic-

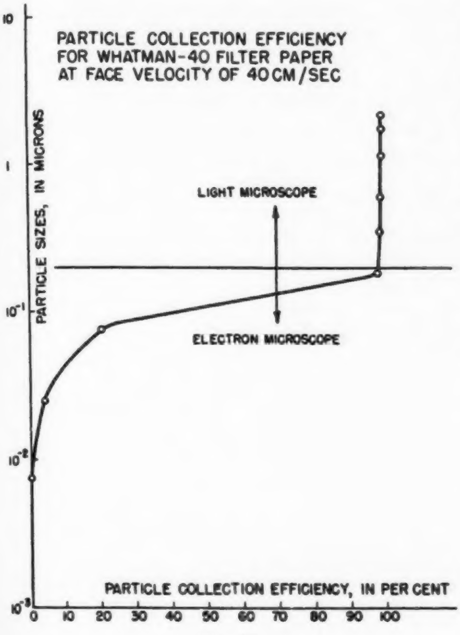

Fig. 16.

roscope at a magnification of 2 x 10^4 was 0.005 to > 0.1 micron. The size range detected with the light microscope was 0.2 to 2.1 microns.

When the data are plotted on linear rectangular coordinates rather than semilogarithmic coordinates, a curve results with a slope of approximately one in the electron microscope range, rounding off rather smoothly to a slope of very nearly infinity for the light microscope range. The light and electron microscope data follow the trend one might expect; i.e., relatively little change in efficiency at certain face velocities throughout the higher light microscope range and a considerably greater decrease in efficiency as the particle size recedes into the electron microscope range. The face velocity chosen for the test represents the most efficient face velocity for Whatman-40 filter paper as shown in the light microscope studies.

The particle collection efficiency for Whatman-41 filter paper at a face velocity of 10 cm./sec. was also determined with both the light and the electron microscopes. The collection efficiency curve for Whatman-41 shown in Fig. 17 is similar to the Whatman-40 curve. The efficiencies of the Whatman-41 paper, however, are significantly greater than those for the Whatman-40 at corresponding particle sizes in the electron microscope range.

Conclusions

THE PARTICLE collection efficiency for the filter media tested varies (1) with particle size, (2) with face velocity and (3) with the filter medium. The Hollingsworth and Vose-70 filter medium and the air cleaning media tested are significantly more efficient in the collection of submicron particles than the Whatman filter papers. However, with proper selection of the face velocity used, a high collection efficiency for the Whatman filter papers can be achieved which is relatively particle size independent in the light microscope range.

In general, the best operating face velocity for each paper, over the size range of 0.18 to 2.1 microns is given in Table II.

In general, the minimum collection efficiency stated in Table II was determined for a particle size of 0.18 micron, while the

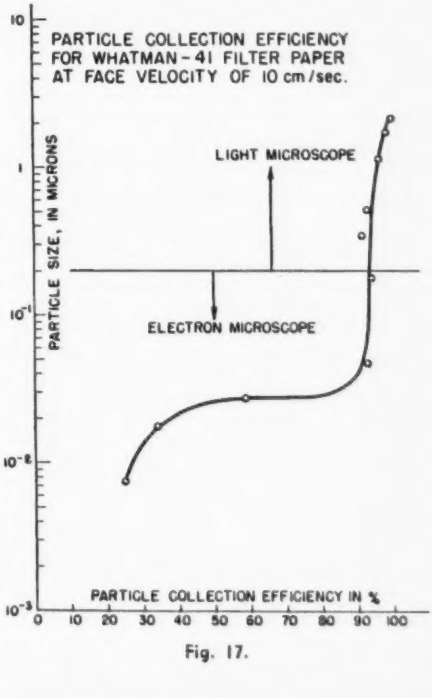

Fig. 17.

TABLE II.
OPTIMUM OPERATING FACE VELOCITY FOR EACH FILTER PAPER

Paper Designation	Optimum Operating Face Velocity, in cm./sec.	Collection* Efficiency Spread, in Percent
W-40	40	98.2-99.6
W-41	100	97.6-98.0
CC-6	40	99.5-99.7
H-70	80	99.4-99.8
AEC-1	20	99.5-99.9
MSA-1106-B	100	99.2-99.8

*This collection efficiency range was established for particle sizes of 0.18 to 2.1 microns with a density of 2.7 gm./cm^3.

maximum collection efficiency was achieved for particles of 2.1 microns in diameter. These optimum face velocities offer a combination of high efficiency for the collection of particulate material with a minimum variation in the collection efficiency with particle size.

When operating at these optimum face velocities the need for knowing the particle size distribution of the toxic or radioactive aerosol for diameters greater than 0.2 micron is eliminated. Efficiency studies, however, have shown that the collection efficiency for particles less than 0.2 micron varies significantly with particle size and thus necessitates the knowledge of the particle size distribution in this particle size range.

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Ten Commandments for Technical Writers

1. Thou shalt remember thy readers all the days of thy life; for without readers thy words are as naught.
2. Thou shalt not forsake the time-honored virtue of simplicity.
3. Thou shalt not abuse the third person passive.
4. Thou shalt not dangle thy participles; neither shalt thou misplace thy modifiers.
5. Thou shalt not commit monotony.
6. Thou shalt not cloud thy message with a miasma of technical jargon.
7. Thou shalt not hide the fruits of thy research beneath excess verbiage; neither shalt thou obscure thy conclusions with vague generalities.
8. Thou shalt not resent helpful advice from thy editors, reviewers, and critics.
9. Thou shalt consider also the views of the layman, for his is an insight often unknown to technocrats.
10. Thou shalt write and rewrite without tiring, for such is the key to improvement.

—ELMER SHAW, in *Science*, April 15, 1955.

The Control of Occupational Health Hazards

CONCEPTS OF ENGINEERING APPLICATION

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Omaha

THE FACT that man and his environment are inseparable has long been recognized. As the environment in which we live, work and play has become more complex, so have the effects of the environment on man created problems which are increasingly difficult for those concerned with the protection and promotion of health and well being. The working environment presents a wide variety of hazards. In fact, there are few, if any, occupations in which environment does not have the capability of causing harm to the worker therein if proper recognition of the condition is not made. In addition to the obvious physical, chemical and biological agents of disease, the working environment may contain factors which have an adverse effect on comfort and well being, if not health. Our concern must not be limited to production line factory workers but our attention also must be given to the worker on the farm, in the small plant, and in all types and classes of occupational activity.

The obligation of all engineers who are concerned with the health and safety aspects of the structures, processes, equipment or devices they conceive is not infrequently overlooked. As pointed out by Hatch[1], "The engineer is required only to make proper use of sound accepted principles of engineering design and otherwise follow the requirements of codes and other regulations. He is not responsible for failures which occur because of inadequate laws. Engineers recognize and accept these responsibilities so fully that they require no elaboration." The responsibilities of engineers with regard to matters affecting health protection and promotion are implicit in the engineering registration acts in the various states as evidenced by Section I of Senate Bill 74, Acts, Regular Session, 45th Texas Legislature: the Code of Practice of the American Society of Civil Engineers (Particular attention is invited to paragraph 8, part 5) and the Canon of Ethics for Engineers.

In order properly to take into consideration the effects of the environment on man, it would appear that the engineer requires some knowledge of man's anatomic, physiological and psychological limitations. Unfortunately, the limited time available in most engineering curricula has precluded to date the inclusion of even cursory information in most cases on this subject. The recommendations of the 1954 President's Conference on Occupational Safety bring to the fore the importance of the further recognition of this responsibility. It should be emphasized that problems of occupational health from an engineering viewpoint were included in the broad scope of the Conference on Occupational Safety and we should not be unduly concerned if some areas commonly thought of as being industrial hygiene engineering (such as noise) are described under safety engineering. Following are quotes of pertinent portions of this report:[8]

"Hazards can be controlled through effective safety engineering applied to standards for machinery and material specifications, standards for building, including adequate fire protection, and standards for materials handling equipment, process revision and many others....

"Designers and manufacturers of machinery, machine tools and equipment should

Presented at Second Industrial Hygiene Conference, The University of Texas, Austin, Texas, May 14, 1955.

give greater consideration to safety requirements....

"Engineers and architects should develop and apply standards for safe and efficient plant layout—greater consideration to safety, health and sanitation and space utilization and employee service areas, as well as to factors of safety and building strength, should be given in original design, construction and remodeling of all industrial structures....

"Engineering colleges should integrate safety engineering principles into all applicable courses in their curricula and establish accredited safety engineering courses....

"Safety engineering studies in basic research should be instituted on special problems on which adequate engineering data are not now available, such as noise, use of isotopes, air pollution, hazardous chemicals, fire and explosion hazards."

The application of engineering and biological sciences is required for analysis of potential occupational health hazards, the development of appropriate and economical controls therefor and the provision of satisfactory general worker environments. The practice of engineering in relation to these human factor problems is not limited to any one segment of the profession, although sanitary and industrial hygiene engineers and safety engineers are or should be specialists in this regard. The details of engineering design for control of occupational health hazards are so vast as to be impossible to repeat here. For reference to some of the available publications and texts, attention is invited to the "Public Health Engineers Bookshelf"[4] and to USAF Pamphlet 160-6-5, "Bibliography of Industrial Medicine and Occupational Health," available from the U.S. Government Printing Office.

THE procedures generally used for engineering design of any type are directly applicable to the control of occupational hazards by engineering means. The usual approach to a design problem is as follows:

1. The acquisition of information about the task—what is to be done, how, where, by whom and under what restrictions either of economy or function. In the case of occupational hazards, one must ascertain exactly what the worker may be exposed to (chemicals such as gases, mist, fumes, dusts, liquids or solvents; physical agents such as ionizing radiation, noise, abnormalities of illumination, temperature, humidity or pressure; biological agents such as bacteria, molds, fungi, etc.; or combinations of these). Information must be obtained as to duration of exposure and what other physiological and psychological factors are involved. The type and nature of waste products and their potential hazard must also be determined.

2. Explore all possible means of achieving the desired result and select the most effective. In the case of occupational hazards control, the following are generally considered: (a) Elimination of the hazardous component or substitution of a less hazardous item wherever possible. (b) Provision of engineering controls such as, but not limited to, the following: isolation or inclosure of the process, use of wet process for dusty operations, local exhaust ventilation of machine or process, general area ventilation, shielding, provision of proper illumination, noise suppression, and such others as may be appropriate for the problem. (c) Provision of personal protective devices such as helmets, respirators, ear defenders, gloves, etc. (d) Combinations of the foregoing.

3. Examine and check the final design. Is the solution really the most effective and economical consistent with the hazard involved? Does the solution impose an unwarranted penalty in added cost, manpower or space requirement? Does the control measure create a new hazard by means of improper disposal of waste products?

A knowledge of the manner in which chemicals enter the body, their fate after entry and their effects on the body is essential for proper design and control as well as evaluation of existing procedures or processes. Similar information is necessary with regard to the physical and biological agents of disease. The engineer must keep in mind the fact that such stimuli as heat, cold, sound, odor, taste and vibration may cause bodily or psychological responses and these must be considered in any integrated design of work areas or work facilities. Attention is being increasingly focused on

"human engineering" and this implies consideration of such factors as comfort and efficiency, as well as the prevention of disease.

A most important factor to be considered in applying engineering principles to the control of occupational hazards is the relationship between duration of exposure and concentration of offending agent in respect to threshold limit values. No rational controls can be established unless the principle underlying development of these values is well understood. This, in turn, necessitates an awareness of the fact that occupational diseases in general result from two types of exposures—acute and chronic. Exposure to high enough concentration of a toxicant may produce dramatic and immediate physiological effect. This is the so-called acute exposure. On the other hand, exposure to small quantities of offending material may allow the gradual accumulation within the body of the material itself or its assimilated by-products until a pathological condition results, sometimes years later.

If the amount taken into the body exceeds the rate of elimination, storage or toxic damage to the tissues results. Threshold limit values represent those concentrations to which a normal person may be exposed for eight hours a day, five days a week over a long time period (30 to 40 years) without demonstrable effects therefrom either during or after the exposure. They are not finite limits between safe and unsafe conditions.[5]

It would be most desirable to have a formula into which we could place such factors as the threshold limit value, the median lethal and lethal dose values, amounts of material the worker is to be exposed to under uncontrolled conditions, correction factors for age of the exposed working population and other conditions and the proposed controls specified in engineering terms and from this derive an answer which would indicate one of the following: perfectly safe for long term continuous exposure, safe for short term exposure, uncomfortable, unacceptable from a comfort viewpoint, dangerous for long term exposure or dangerous to life or health for short term exposure. In the absence of such a formula, good engineering judgment and practice will have to be applied to each situation.

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Kemper Fellowship

A fellowship in Industrial Hygiene, leading to the degree of Master of Public Health (Industrial Health), is offered by The James S. Kemper Foundation. It covers tuition and academic fees at the School of Public Health, University of Michigan, and offers the successful candidate reasonable living allowances during residency at the University. The James S. Kemper Foundation was established in 1942 by insurance companies in the group managed by James S. Kemper of Chicago. A purpose of the Foundation is to aid worthy persons to take advantage of educational opportunities particularly helpful to an insurance career. Applications for the Kemper Fellowship and for Admission to the School of Public Health may be obtained by addressing the Dean, School of Public Health, University of Michigan, Ann Arbor, Michigan.

A Constant Flow Suction Unit

—FOR AEROSOL SAMPLING WORK

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A suction unit has been developed and tested which will automatically draw air into filter samplers at a preset constant rate in spite of wide variations in the resistance of the collecting media. Two models are described, one having a fixed flow rate of 10 cfm and the other being adjustable between 1 and 15 cfm. Components were selected to make them portable and to enable them to operate under adverse field conditions. Flow control is achieved by using a vacuum operated valve ahead of the pump to compensate for upstream pressure variations and maintain constant pumping conditions. In performance tests the units kept the flow constant within 5% while the pressure drop at the intake was increased from 0 to nearly 8 in. of Hg.

A SUCTION unit which would automatically draw air into a collecting filter at a constant rate regardless of the amount of deposit on the filter and the consequent resistance to air flow was needed in the aerosol sampling program at the U. S. Naval Radiological Defense Laboratory. Such a unit would make possible accurate sampling in remote locations, without someone being present to observe and manually adjust the flow rate. Also such a unit would be useful in laboratory work since the flow rate (measured at atmospheric conditions) would not be affected by the type of filter used, the length of connecting hose, and the presence or absence of a calibrating flow meter.

The suction unit had to meet several specifications. For isokinetic sampling in moving air streams, an easy way of adjusting the flow was needed so that the unit could be set at flow rates between 1 and 15 cfm, and produce a maximum suction of 6 to 8 in. of Hg. For measuring aerosol concentrations in free air, a fixed flow rate of 10 cfm was desired with a maximum suction of 8 in. of Hg. Flow rates were to be maintained within 5% of set values and a flow monitoring device was to be provided which would show whether the flow rate changed during a collection run and for how long. Finally, the unit had to be portable and operate under a wide range of humidity, temperature, atmospheric corrosion, and fungus growth conditions as found in both the United States and the tropics.

Description

THE SUCTION UNIT was built in two models to meet the need for both fixed and adjustable flow rates. The adjustable unit is

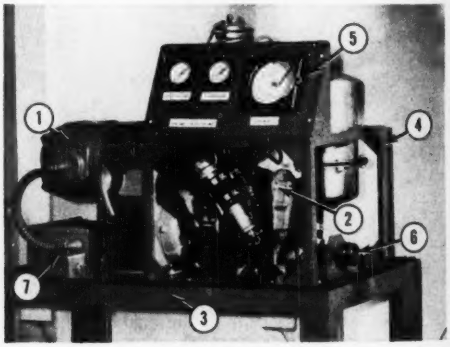

Fig. 1.
Adjustable flow rate model of suction unit showing (1) variable speed motor drive, (2) air pump, (3) welded steel base, (4) instrument support frame, (5) instrument panel, (6) inlet hose connection, (7) motor start switch.

shown in Fig. 1, and has the air pump directly connected to a ¾-hp. variable speed motor drive, and is mounted on a welded steel base. Flow rates are varied by turning the handle on the side of the motor drive, which changes the setting of some variable pitch pulleys inside, and in turn changes the speed of the pump.

The fixed flow rate unit is shown in Figs. 2 and 3. It has the air pump belt connected to a 1-hp. 3450-rpm motor, and is mounted on a light weight wooden sled which could be dragged over the ground and fastened down with stakes at land stations. For shipboard installations, the wooden sled was fitted with steel legs that could be welded to the decks.

In other respects the two models are identical. Incoming air passes through a protective filter and vacuum control valve to the air pump, and thence out through a muffler and a Venturi tube. The protective filter and vacuum control valve are mounted on an instrument support frame. Gages for measuring the filter vacuum and control vacuum, and for recording the flow rate are mounted on an instrument panel above the support frame as shown in the figures. Also visible are the vacuum relief valve, vacuum sensing valve, inlet hose connection and motor start switch.

For ease in assembly and to reduce galvanic corrosion, the major components were connected together with wire reinforced flexible hose. Minor connections were made with either fabric reinforced hose, or Tygon tubing. Aluminum components and piping were used wherever possible to keep down the weight. This was especially true of the fixed flow rate unit which was designed for land locations.

Protective covers, which are not shown, were provided when the units were to be exposed to the elements. These were made of corrugated galvanized iron and shaped like large rural mail boxes, with flat sides, rounded top, and flat ends. They were sealed to the suction unit bases with sponge rubber gaskets, and held in place with Simmons fasteners, shown in Figs. 2 and 3. Louvers fitted with Fiberglas filters were provided in the ends of the covers to ventilate the motors and pumps and at the same time protect them from dust and radioactive contamination.

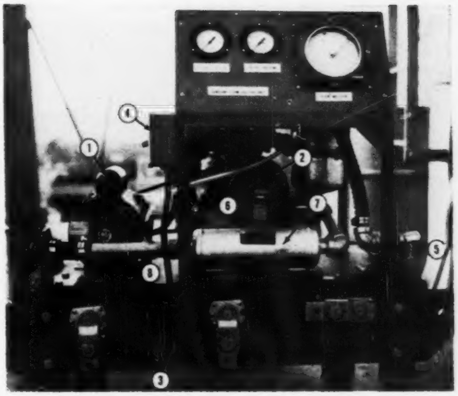

Fig. 2.
Front view of fixed flow rate model of suction unit showing (1) motor, (2) air pump, (3) wooden base, (4) motor start switch, (5) inlet connection, (6) sensing valve, (7) muffler, (8) Venturi tube.

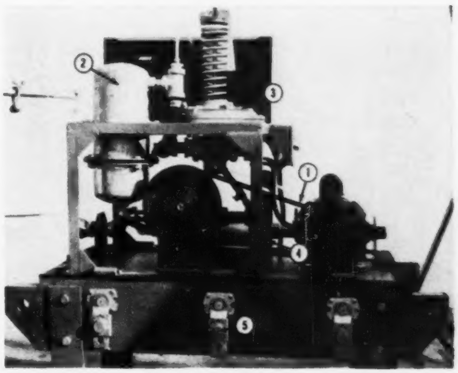

Fig. 3.
Rear view of fixed flow rate model of suction unit showing (1) belt drive, (2) protective filter, (3) vacuum control valve, (4) vacuum relief valve, (5) Simmons fastener for securing protective cover.

Principle of Operation

THE SCHEME used for maintaining a constant flow rate is basically very simple. The effect of the expansion of the air with increased suction is compensated for by having a control valve in series with the collecting filter which automatically opens and closes to keep the total suction at the pump intake constant. By this means the

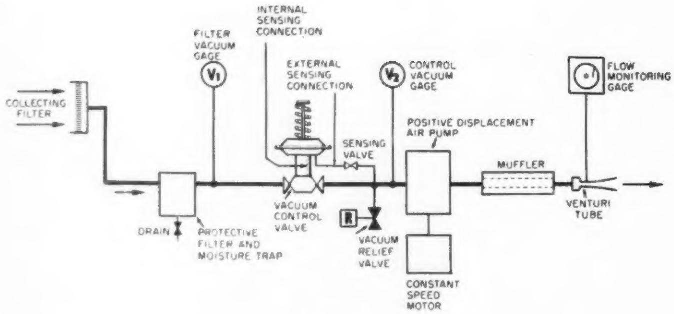

Fig. 4.
Schematic flow diagram of Constant Flow Suction Unit.

density of the air entering the pump is kept constant, so that as long as the pump has a fixed displacement and operates at a constant speed the flow will be constant.

Referring to the schematic flow diagram in Fig. 4, if the control vacuum (V_2) is set at 8 in. of Hg. and the filter vacuum (V_1) is only 1 in. of Hg., the control valve will provide a compensating pressure drop of 7 in. of Hg. If, for some reason, the resistance of the filter system (V_1) then goes up to 5 in. of Hg., the control valve will automatically open to provide a compensating pressure drop of only 3 in. of Hg., and thus keep the control vacuum (V_2) at 8 in. of Hg. to maintain constant pumping conditions and hold the flow rate constant.

The use of only rugged mechanical components is one of the best features of this flow control scheme. No electrical or electronic devices are required, and when necessary even the customary electric motor may be replaced with one that is gasoline or compressed air driven.

The main limitation of this scheme is that the control vacuum must always be greater than the filter vacuum to permit the control valve to compensate for changing air densities. Normally this limitation presents no problem since it is possible to estimate what the maximum likely pressure drop across the collecting filter will be, and to set the control vacuum a little higher. If the filter vacuum should exceed this value, control will be lost, and the filter vacuum and control vacuum will then increase together. At that point the flow monitor will indicate a noticeable drop, so that the user will know what has happened. As a further precaution a vacuum relief valve is provided so that if the intake is completely blocked the suction cannot become great enough to damage the pump or overload the motor.

Other limitations of this flow control scheme are the need for a sensitive vacuum control valve with a flat response to upstream conditions, a constant speed motor, and a pump which maintains a constant volumetric displacement while it is operating.

The flow monitoring system consists of a Venturi tube and a recording vacuum gage. The Venturi tube is placed at the outlet of the system so that the air going to it will always be at a constant pressure and be unaffected by the varying suction on the collecting filter. Also in this location, a single measurement of the suction at the throat shows the difference in pressure between the throat and the end of the tube. A Venturi tube was used instead of an orifice plate so that an easily measurable signal could be obtained without producing an objectionable back pressure on the pump. The muffler connected ahead of the Venturi tube reduces the noise from the pump, and helps smooth out the pulsations and turbulence in the air before it reaches the Venturi tube.

Components

THE SELECTION of proper components was very important to the success of the basic control scheme as well as to the performance of the suction unit under anticipated field conditions. Since many of the components are familiar, only the more important or unusual ones will be discussed.

Referring again to the schematic diagram it is evident that a protective filter was needed which would keep dirt and water out of the control valve and pump, prevent radioactive aerosols from contaminating the rest of the suction unit in case of a break in the collecting filter, provide a check on the collecting filter, and have a low pressure drop. These requirements were met by

using a $\frac{3}{4}$-in. Dollinger vacuum pipeline filter. In tests, this filter had a pressure drop of only 2.2 in. of water with an air flow of 15 cfm (measured at atmospheric conditions), retained virtually all of a fine water spray introduced into the air stream without wetting the filter cartridge, and retained 99% of a small test quantity of type S. F. carbonyl iron powder* (mean particle diameter 3μ) without appreciable increase in pressure drop. For corrosion resistance the case of this filter was hot dip galvanized and dichromated, and the smaller metal parts were zinc plated and dichromated.

As previously stated, a sensitive vacuum control valve was needed with a flat response to upstream conditions over a range varying from atmospheric pressure to as close to the control vacuum as possible. This control valve also had to operate on the available pressure drop without use of auxiliary power, be easily adjustable, operate in any position, and be light and compact. To meet these requirements a special valve was built by the Charles M. Bailey Company. This valve had a $1\frac{1}{8}$-in. diameter inner port, a piston type inner valve, a $7\frac{3}{4}$-in. diameter diaphragm button, and a spring 8 in. long. It had an aluminum body, and a ribbed aluminum diaphragm case with narrow flanges. For corrosion resistance the aluminum was annodized and dichromated, and all metal parts in contact with it were either made of stainless steel, or were zinc plated and dichromated.

An interesting feature of the control valve is that it is provided with an internal sensing connection between the diaphragm case and the downstream side of the valve body, as well as an external sensing connection from the diaphragm case to a point near the intake to the pump. In testing the characteristics of a prototype control valve it was learned that if the internal connection was used alone at high flow rates, the flow into the suction unit would increase slightly with increasing filter vacuums, while if the external connection was used alone, the flow would decrease slightly with increasing filter vacuums. Further investigation showed that the vacuum at the downstream side of the valve body was as much as 2 in. of Hg. *greater* than the vacuum at the intake to the pump, indicating a Venturi effect within the valve body. To take advantage of this effect a "sensing valve" was provided in the external sensing line which can be adjusted to combine the best combination of internal and external sensing performance. Further tests on other vacuum control valves have not demonstrated this effect to the same degree and it may be possible to eliminate the sensing valve in future suction units.

The flow control scheme required a motor which would maintain a constant speed under load, since the output of the pump is proportional to its speed. Fortunately most capacitor start, 60 cycle, single phase motors are built to maintain their speed within 2% with voltage changes of plus or minus 10%, providing of course that the frequency remains constant, so that this was no problem. The motor also had to be light and compact and resistant to damage from fungus and corrosion. Lightness was achieved in the adjustable flow rate unit by using a variable speed motor drive with an aluminum case manufactured by the U.S. Electrical Motors Company, and in the fixed flow rate unit by using one of the new Form G, light weight General Electric appliance motors. Resistance to fungus growth and corrosion was attained by having the windings impregnated with fungus resistant varnish, by using splashproof motors, and by plating critical mechanical parts with zinc or cadmium.

From early tests with this type of suction unit, it was apparent that in order to maintain a constant flow rate it was necessary not only to maintain a constant suction at the intake of the air pump and to run the pump at a constant speed but also to have a pump whose characteristics remained constant in operation. A rotary positive displacement blower of the Roots type had been chosen for this application since it runs at a relatively high speed, is small for its capacity, will produce the necessary suction, and does not require the use of oil in the rotor case which would affect cold climate starting. This type of blower is widely used for supercharging engines, and as the metering element in large gas meters. During these tests it was noticed that the air flow into a stock blower at 8 in. of Hg. suction dropped 19% during the first half hour

*Manufactured by General Analine and Film Corporation, Antara Chemicals Division.

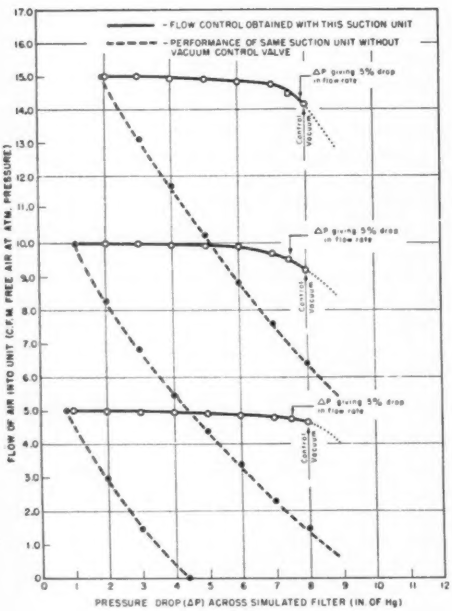

Fig. 5.
Effect of changes in filter resistance on constancy of air flow with the control vacuum set at 8 in. of Hg.

of operation as it warmed up to a stable operating temperature. This drop was far from the permissible 5% deviation. This stock blower had an aluminum case and cast iron rotors, and it was apparent that a differential expansion had occurred between the rotors and the case, increasing the clearances and the leakage. To meet this problem a special blower was obtained from the Sutorbilt Corporation in which both the rotors and the case were made of Ni-resist No. 5, a cast iron alloy with a low coefficient of thermal expansion. This alloy also solved the corrosion problem since it is relatively resistant to attack from salt spray.

The need for a small, recording vacuum gage that would respond to the suction available from the throat of the Venturi tube was met by using a Dickson "Minicorder." This instrument has a 4-in. circular chart, a full scale reading of only 10 in. of water, and weighs only five pounds. For this application it was equipped with a capped fountain type pen and a spring loaded pen arm so that it would not be affected by tilting or vibration. The case was fully gasketed, so that when used in a humid atmosphere, a bag of dessicant could be put inside to prevent corrosion and keep the paper dry.

The Venturi tube represents a novel departure from ordinary manufacturing procedures. In trying to make it cheaply, it was discovered that satisfactory results could be obtained by casting the inner profile and reaming the throat to size. In comparison with a tube having a fully machined inner profile, the resulting tube had slightly less pressure recovery, and hence slightly more line loss. The total pressure drop from having it in the system, however, is still only 1 or 2 in. of water.

Performance Results

FIVE TESTS were conducted on the suction unit to evaluate its performance under different operating conditions. In order to measure the extent to which the constancy of air flow is affected by changing filter resistances, a manually-operated valve was connected to the inlet to simulate a filter, and a precision Flowrator was connected ahead of the valve to measure the air going into it. Vacuums were measured with mercury manometers. The control vacuum was set at 8 in. of Hg., the external sensing connection was closed and the unit was allowed to run until the pump had reached a stable operating temperature. The test was run at 15, 10 and 5 cfm; the results are plotted as solid curves in Fig. 5. For comparison the vacuum control valve was then removed and the same tests repeated to show the performance of a conventional suction unit with the same type of air pump. The results of these latter tests are plotted as dashed curves in Fig. 5 and illustrate the great advantages of the constant flow feature. Returning to the solid curves, it was expected that with a spring-loaded vacuum control valve the flow would drop slightly as the filter resistance was increased causing the valve to open and compress the spring. It is significant from these tests, however, that with the control valve used the drop in flow was negligible at a filter vacuum of 2 in. of Hg. below the control vacuum, and amounted to only 5% at ½ in. of Hg. below the control vacuum. This is probably the

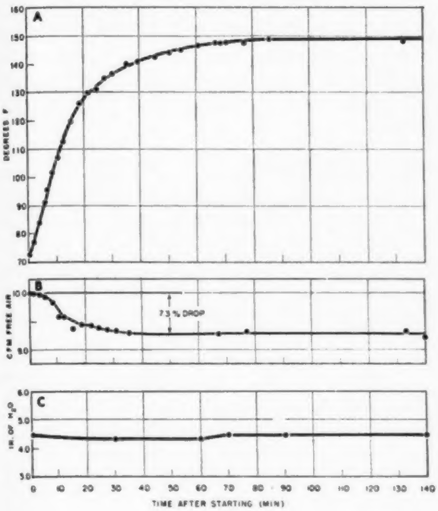

Fig. 6.
Effect of pump temperature on constancy of air flow.

best that can be expected in a portable suction unit of this type with a spring-loaded vacuum control valve; however, it should be pointed out that for stationary installations other types of vacuum control valves are available that will give even better performance.

The response rate of the control valve was tested by suddenly opening or closing the manually-operated valve on the inlet to the suction unit, and observing the effect on the Flowrator. In this test the control vacuum was set at 8 in. of Hg., and the blower speed was adjusted to give a flow rate of 10 cfm. When the filter vacuum was suddenly changed from 1 to 5 in. of Hg., there was a lag of about 1 sec. before the Flowrator returned to its original setting. This lag was probably the time required for the control valve to readjust itself. There was no noticeable overshooting or oscillating about the control point.

The degree to which the constancy of flow is affected by the temperature of the air pump is shown in Fig. 6, curves A and B. In this test an ironconstantan thermocouple was bolted to the top of the pump case, midway between the inlet and outlet sides, and temperatures were observed on a Leeds and Northrup Type K potentiometer calibrated to read directly in degrees F. The suction unit had been sitting overnight so that the pump was initially at room temperature. The control vacuum was set at 8.6 in. of Hg., and not changed during the test. The filter vacuum was not varied, and the blower speed was held constant by observing the blower shaft with a Strobotac, and adjusting the motor voltage before each reading until the shaft speed was synchronized with the pulsating stroboscopic light. The flow rate was observed with a precision Flowrator connected to the inlet of the suction unit. As curve B in Fig. 6 shows, there was a 7.3% drop in the flow rate that occurred almost entirely in the first 30 min. Curve C shows that the flow monitor reading dipped slightly, and then returned to its initial value, indicating that it was affected about equally by the drop in flow rate, and the increased temperature of the air in the Venturi tube. If this drop in the flow rate is compensated for by setting the initial value about 5% higher than called for, the deviation will then be within the required plus or minus 5%. It should be pointed out that a slight drop of this sort is inevitable in a rotary pump without oil-

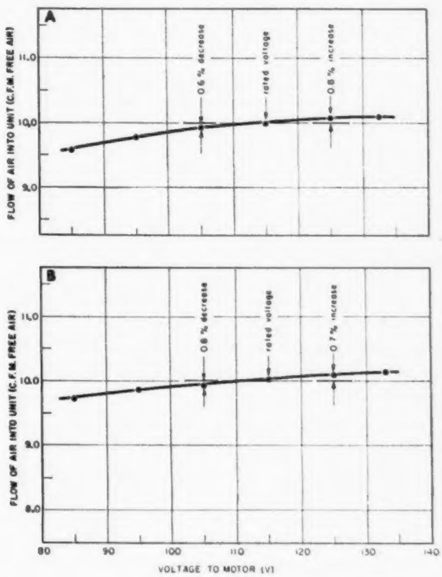

Fig. 7.
Effect of motor voltage on constancy of air flow.

immersed rotors, but can be further reduced when necessary by using a type of pump in which there is less leakage.

Fig. 7 shows the effect of motor voltage on the constancy of air flow into both the fixed and adjustable suction units. With the 1 hp., 3450 rpm General Electric motor there is 0.8% increase and a 0.6% drop as the voltage is increased or decreased 10 v. from the rated 115 v. With the ¾-hp. U.S. Varidrive motor there is a 0.7% increase and 0.8% drop with corresponding changes in voltage. In these tests the pump had previously been brought to a stable operating temperature, the control vacuum was set at 7.8 in. of Hg. in one instance and 6.0 in. of Hg. in the other and the filter vacuum was not varied. The voltage to the motor was changed by means of a Variac, and measured with an alternating current voltmeter.

Acknowledgements

THE AUTHORS are indebted to F. J. SISK and T. C. GOODALE of the U.S. Naval Radiological Defense Laboratory for reviewing the work and offering valuable suggestions, and to R. J. KROGFOSS of the Charles M. Bailey Company for help in designing special components.

Department of One-Paragraph Reports

A WORKMAN was centrifuging a mixture of benzyl cyanide, sodium chloride, and a small amount of sodium cyanide. He had finished the centrifugal separation and was digging the cake out into an open vessel which contained a small amount of acid water. He became dizzy and faint and decided to go outside for fresh air. He walked with a staggering gait and appeared drunk, although there was no question of his having taken any alcohol. He went for help to another workman in a nearby building, and was unable to stand when he got there. When seen in the plant hospital, he was pale, with a weak, rapid pulse and profuse sweating, and appeared to be in a state of shock. He recovered rather rapidly on being put to bed and kept warm, and he was perfectly normal one hour later. The next day he had a severe headache, became nauseated and vomited violently, but, after staying in bed for two days, was well and able to return to work. A visit to the scene of the accident revealed no symptoms in other men in the same building; the man who completed the job suffered no symptoms. There was a strong odor in the building, somewhat suggestive of bitter almonds, but it was not possible to say whether this came from the benzyl cyanide or hydrogen cyanide gas. It was determined that the sodium chloride-sodium cyanide mixture contained approximately 1% sodium cyanide, and gas bubbles could be seen around the edge of the solid.

Atmospheric Pollution Study of a Non-Industrial Area

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THIS PAPER concerns a study of relatively clean air in a non-industrial area composed of open countryside and small suburban development.

The data to be discussed are basic to any air pollution study in that the effects of any nearby industry are negligible and we are in the fundamental realm of country air, which is so often referred to as clean, fresh and invigorating.

The study findings provide necessary background data and offer partial answers to several pertinent questions such as: (1) How clean is so-called clean air in a non-industrial area? (2) How does the particulate loading vary from that in a heavily industrialized city? (3) What is the significance of varying weather conditions? (4) To what extent is pollution in the country related to pollution in relatively close industrial areas?

The reason for the study was not solely academic but was, in a large part, owing to a letter dated November 28, 1952, addressed to our Division by Peter J. Watson, President of the Blue Water Highway Property Owner's Association. It reads as follows:

"Dear Sir: Representing the home-owners and residents of the St. Clair River District and particularly East China Township, site of the Detroit Edison power plant now under construction as well as a proposed Michigan Iron and Coke Company plant consisting of one or more blast furnaces and 50 or more coke ovens, we should like to request a survey to determine the status of atmospheric pollution in this district.

What we have in mind is a survey that would indicate existing dustfall and possibly other yardsticks of air pollution as of the present status, conditions after the Detroit Edison plant begins operations, and conditions prevailing if and when the Michigan Iron and Coke plant has gone into operation.

We feel that an official survey of this nature would serve as an authoritative and equitable guide that would make facts available to not only the residents but also the above named industries and help them in planning their pollution control equipment and procedures. It is also our thinking that data collected in this survey would serve to indicate the extent of "normal" pollution in a better class outlying residential area and therefore provide a useful reference point in the International Joint Commission survey now being conducted in the Detroit-Windsor area by United States and Canadian Public Health officials. For that reason the groups interested in the Detroit survey might upon your request be willing to cooperate to the extent of providing consultation and possibly equipment.

If data are to be collected prior to the operation of the Detroit Edison power plant the work would need to get underway as power production at this plant is scheduled for July or August of 1953.

If you care to discuss this project with someone who is acquainted with its technical phases you may wish to contact Mr. Fred Mallette or Mr. Frank A. Patty, both of whom are well acquainted with the situation.

Respectfully yours,"

Mr. Watson's statement of the case was simple and exact. One source of air pollution was the new, extensive Detroit Edison Company power plant then being completed. Another possible source, the proposed Michigan Iron and Coke Company, was in the planning stage, with the plant site already purchased. A suburban area consisting mainly of farmland and river front homes was faced with the inevitable economic loss due to the relocation of industry—and with the possibility of problems

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Presented at the Industrial Health Conference, Air Pollution Division, AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, Hotel Sherman, Chicago, Illinois, April 28, 1954.

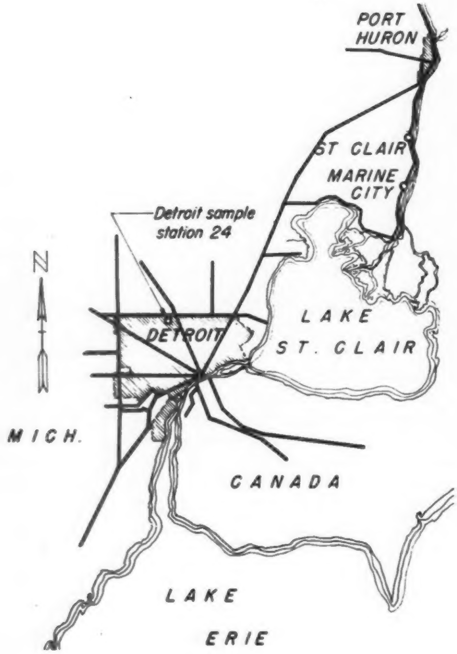

Fig. 1.
Geographic relationship of St. Clair-Marine City area to Detroit.

affecting the enjoyment of one's property as well as health.

A one-month study was planned and was started on April 15, 1953, after much consideration had been given to the various methods of sampling which would enable the determination of a satisfactory pollution index of the area.

The gross air sampling unit using Mine Safety Appliance Company, Type S, unimpregnated pleated filters was selected for the continuous (24 hour filter period) sampling of particulate matter at eight stations and the Thomas Autometer was to be used at three stations for sulfur dioxide determinations. In addition dust counts were scheduled for each station, using the Greenburg-Smith impinger and standard light field counting technique.

Dust fall measurements were intentionally omitted because of the short sampling period which would not enable the collection of data over a long enough time spread for proper interpretation. Also, there was some doubt concerning the validity of such measurements.

The area studied is outlined in Fig 1. which indicates the proximity to Detroit (about 40 miles) where the International Joint Commission's Technical Advisory Board on Air Pollution was, and at the time of this writing is still, engaged in a study of air pollution in the Detroit area. Fortunately, these concurrent studies enabled the comparison of some data.

Fig. 2 is a more detailed map of the East China Township area which, as is shown, is bordered by the City of St. Clair on the North, Marine City on the South, and the St. Clair River on the East. The eight stations are pinpointed as are those stations (No. 1, No. 5, and No. 8) where sulfur dioxide samples were collected.

A brief description of the eight stations follows:

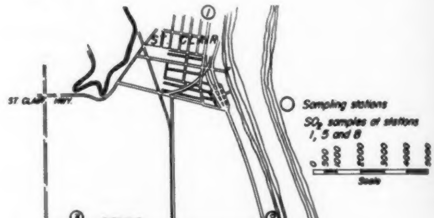

Fig. 2.
Samples taken in the St. Clair-Marine City area.

STATION NO. 1: City of St. Clair, about 40 miles northeast of Detroit, population 4,098. Industry limited, consisting of large salt manufacturing plant, moderately sized production machine shop, and a few small job shops where welding and machining is done. The sampling station was located in the commercial-residential section of the city, on the northeast corner of the post office block.

There was no industry in the immediate neighborhood.

STATION NO. 2: This station was located on the northeast corner of Puttygut and River Road, a short distance from the St. Clair River. It was chosen because of its proximity to the proposed site of the Michigan Iron and Coke Company, with the area at the time of the sampling comprised mainly of farm land and a limited residential section.

STATION NO. 3: This station was located on Puttygut Road in the neighborhood of a small plastic molding plant, but otherwise completely surrounded by open countryside limited to farming.

STATION NO. 4: This station was located on the southwest corner of King and Reamer Roads, about one mile west of the Detroit Edison Company's power plant and completely surrounded by farms.

STATION NO. 5: This station was located in a residential area on the shore of the St. Clair River. Both the new Detroit Edison Company structure and the proposed site of the Michigan Iron and Coke Company were situated nearby.

STATION NO. 6: This station was located on the property of the Marine City Water Treatment Plant adjacent to the St. Clair River, and was surrounded by open fields on three sides.

STATION NO. 7: This station was located on Meisner Road between King Road and the railroad tracks. The surrounding area consisted of farm land with a few homes nearby.

STATION NO. 8: Marine City has a population of about 4,300, its industry consisting of a large metal fabricating plant and a few small industrial establishments. The sampling unit was located in the downtown commercial-residential district with no industry in the immediate vicinity.

Description of Sampling Equipment

AIR-BORNE particulate matter was continuously sampled at all eight stations with the use of a high volume sampling unit. The instrument consists essentially of an Electrolux blower, a rotometer type flow meter, and an inlet adapter designed to hold a Mine Safety Appliance Company Type S, pleated filter. The flow rate averaged about 70 cubic feet of air per minute for all units used.

The high volume sampling units were mounted on Detroit Edison Company utility poles, 10 feet above grade level and on cross arms installed by the company. Drop cords were connected to the overhead power lines for power and each sampling unit was protected from rain and snow with a metal shield.

Gross air samples were collected continuously 24 hours per filter, from April 15, 1953, to May 15, 1953. Sulfur dioxide concentrations were evaluated at stations No. 1, No. 5, and No. 8 with a Thomas Autometer which was housed in a mobile laboratory.

Dust samples for counting were collected at each of the stations using a standard Greenburg-Smith impinger. The quarter field Dunn cell and standard microscope technique using a light field were used for counting. Particle size determinations were not made.

Laboratory Techniques

FOLLOWING collection of the high volume air samples, they were submitted to our laboratory for total weight determinations and 60 of the 240 filter samples were then sent to the Division of Occupational Health, U.S.P.H.S. laboratory for spectrographic analysis.

Unfortunately, time limitations make it necessary to eliminate discussion of the laboratory techniques used. However, detailed descriptive information concerning the laboratory procedures has been published by Keenan and Byers.[1]

Results of Study

A. PARTICULATE MATTER: Particulate matter was collected simultaneously and continuously at all eight stations for the period starting April 15, 1953, and ending May 15, 1953. As expected, the dust loadings

TABLE I.
COMPARATIVE LOADINGS OF TOTAL PARTICULATE MATTER (MICROGRAMS PER CUBIC METER OF AIR) EIGHT STATIONS—ST. CLAIR-MARINE CITY AREA. 1 STATION—DETROIT

Station	Location	Area	Minimum	Maximum	Median
1	St. Clair-Marine City	Urban	38.0	550.7	156.8
2	" " "	Rural	22.4	481.2	91.0
3	" " "	Rural	13.8	326.7	97.2
4	" " "	Rural	12.4	436.0	100.5
5	" " "	Rural	10.8	292.3	85.9
6	" " "	Rural	19.3	188.5	58.9
7	" " "	Rural	12.8	933.7	118.0
8	" " "	Urban	37.8	794.2	164.9
24	Detroit	Urban	72.8	762.0	195.0

Note: All sampling stations run concurrently.

determined in Marine City and in the City of St. Clair were considerably higher than those determined in the neighboring rural and suburban areas (See Table I).

At the time of the St. Clair-Marine City study, similar sampling was being conducted at Station No. 24 in Detroit (International Joint Commission data). Station No. 24 is described as being completely residential, there being no industry within a one-mile radius. The immediate area was occupied by low income families who lived in frame houses, shacks and converted Quonset huts. Station No. 24 was found to exhibit the lowest median particulate matter loading of all of the Detroit stations studied in 1952[1] when median values as high as 400 micrograms per cubic meter were found. As shown in Table I, the median value for particulate matter determined at Station No. 24 was 195.0 micrograms per cubic meter of air.

This compares with the loadings of 156.8 and 164.9 micrograms per cubic meter determined in St. Clair and Marine City respectively. Considering the concentrations of industry in Detroit and the resulting effect on the Station No. 24 findings, the dust loadings determined in St. Clair and Marine City were surprisingly high. Thinking in terms of a possible maximum allowable

TABLE II.
TOTAL WEIGHT OF PARTICULATE MATTER COLLECTED DAILY AT EIGHT SAMPLING STATIONS (MICROGRAMS PER CUBIC METER OF AIR)

Date		Station number								
Month	Day	1	2	3	4	5	6	7	8	Mean (arithmetic)
April	15	137.5	34.4	33.2	18.5	26.5	24.2	——	41.1	39.4
	16	127.3	91.0	97.2	92.2	90.1	111.4	129.8	122.7	97.4
	17	248.5	247.5	180.5	162.2	134.8	162.4	22.2	230.5	173.6
	18	——	91.6	119.0	100.5	37.7	53.9	74.6	164.9	80.3
	19	40.4	35.3	17.4	14.3	13.8	25.0	——	39.1	23.2
	20	45.3	48.5	21.7	12.4	10.8	23.5	12.8	41.1	27.8
	21	186.3	201.6	114.9	91.9	93.5	102.5	97.3	238.7	140.8
	22	351.1	406.7	326.7	291.9	208.1	——	352.6	329.3	283.3
	23	228.5	22.4	250.9	293.6	119.4	——	461.0	284.7	207.6
	24	94.6	63.6	69.3	46.9	43.0	41.6	43.9	70.3	59.2
	25	101.2	57.9	49.0	38.8	48.7	58.9	43.8	90.0	61.0
	26	38.0	24.6	17.0	14.5	19.8	19.3	19.2	37.8	23.8
	27	122.8	34.8	13.8	27.7	13.7	33.7	29.7	47.6	40.5
	28	104.6	63.9	41.2	89.5	30.8	46.5	108.7	152.6	79.7
	29	130.7	36.8	73.6	163.0	36.9	34.7	144.7	222.0	80.3
	30	141.5	101.8	113.8	100.6	85.9	31.7	119.5	108.4	100.4
May	1	156.8	71.0	74.3	82.2	57.0	46.9	54.9	114.7	82.2
	2	72.5	27.9	25.0	33.4	25.7	22.2	26.0	54.4	35.9
	3	550.7	65.9	61.8	52.0	67.7	62.9	58.7	115.6	154.4
	4	258.6	162.9	156.6	175.4	292.3	117.0	158.9	212.1	191.7
	5	253.2	158.8	134.3	193.2	112.2	132.9	193.7	219.9	174.8
	6	282.9	252.5	174.9	274.3	169.8	188.5	385.3	552.7	285.1
	7	236.9	194.7	200.0	375.5	132.9	164.2	601.7	189.8	239.5
	8	313.3	200.4	158.6	436.0	101.9	138.4	933.7	794.2	384.6
	9	263.0	481.2	318.1	214.8	149.5	163.7	294.8	409.9	286.7
	10	207.9	191.1	155.7	134.0	122.8	111.9	111.4	173.4	151.0
	11	265.6	200.0	223.3	134.0	165.5	170.3	270.6	237.5	208.4
	12	125.8	87.3	65.6	86.4	52.6	48.7	48.6	——	64.4
	13	——	——	——	——	——	——	——	——	——
	14	196.1	142.3	95.8	147.0	125.6	162.8	118.0	——	123.5
	15	——	——	——	——	——	——	——	——	——

Note: Underline indicates median value.

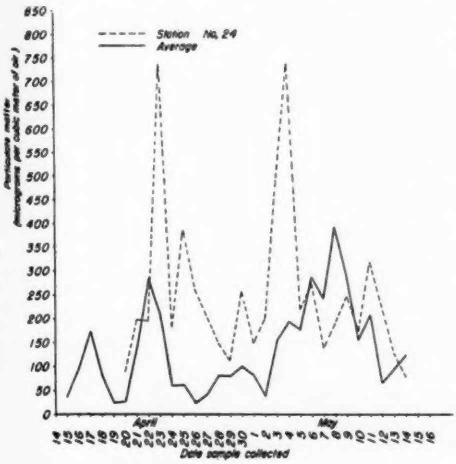

Fig. 3.
Daily collection of particulate matter comparison of Station No. 24 (Detroit) with average of eight St. Clair-Marine City area stations.

concentration value based on particulate loading in a so-called clean, industry-free area, it appears that the similarity of values determined in the Marine City-St. Clair area and in Detroit presents a problem concerning one's interpretation of just what clean air is and how dirty it should get before it's considered polluted. Unfortunately, with the exception of Station No. 24, no other simultaneous sampling was being conducted in the Detroit area. The lack of such data invalidates most comparisons that would normally be made. Comparison with the extensive data previously determined in the Detroit River area study is not justified. However, the high readings determined in the St. Clair-Marine City area as tabulated in Table II indicate that despite the remoteness of the location, the so-called clean areas can, and do, exhibit relatively high dust loadings.

A day-to-day comparison of the average of the eight stations with Station No. 24 (Detroit) is plotted in Fig. 3. With the exception of a few values, there is no decided similarity in trend. Additional comparative data would be necessary before any definite conclusions concerning over-all relationships could be reached.

Conclusive data of this type are desirable for several reasons. Depending upon meteorological factors, it might be possible to predict over-all pollution levels in neighboring areas on the basis of study data in

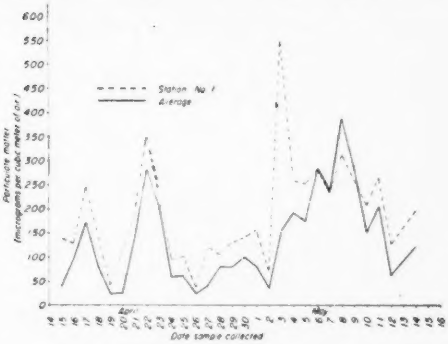

Fig. 4.
Daily collection of particulate matter comparison of Station No. 1 with average of eight stations.

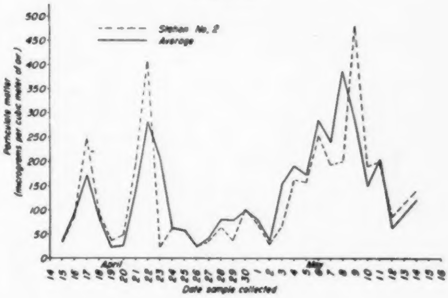

Fig. 5.
Daily collection of particulate matter comparison of Station No. 2 with average of eight stations.

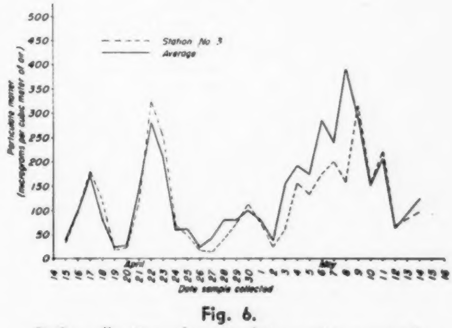

Fig. 6.
Daily collection of particulate matter comparison of Station No. 3 with average of eight stations.

one area. Also, industry's contribution to the over-all pollution level in an industrial area may possibly be more closely evaluated. Considering the St. Clair-Marine City study results, it appears that the so-called "blank"

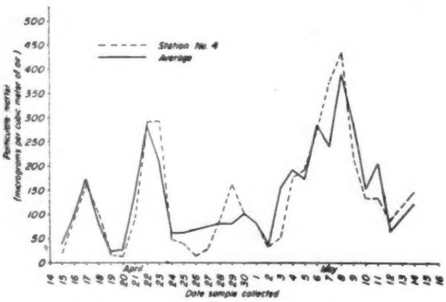

Fig. 7.
Daily collection of particulate matter comparison of Station No. 4 with average of eight stations.

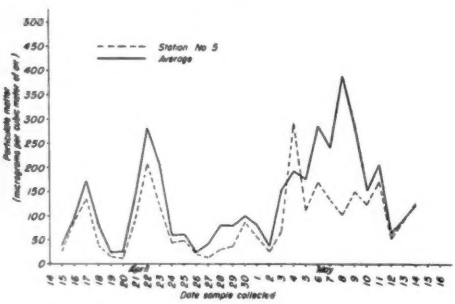

Fig. 8.
Daily collection of particulate matter comparison of Station No. 5 with average of eight stations.

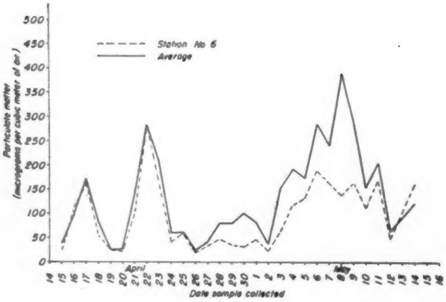

Fig. 9.
Daily collection of particulate matter comparison of Station No. 6 with average of eight stations.

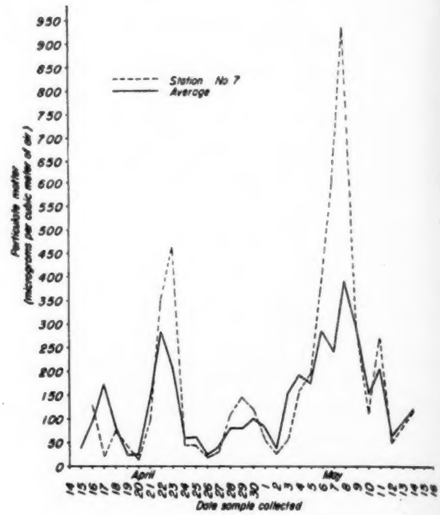

Fig. 10.
Daily collection of particulate matter comparison of Station No. 7 with average of eight stations.

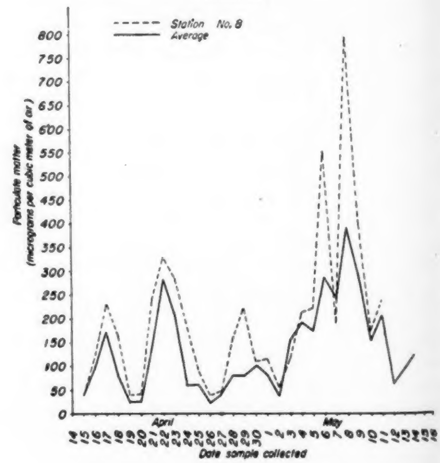

Fig. 11.
Daily collection of particulate matter comparison of Station No. 8 with average of eight stations.

pollution level in an industry free environment is often appreciable.

On the basis of the consistent data obtained, the high volume air sampler proved itself to be a worth-while sampling instrument. Little trouble was experienced dur-

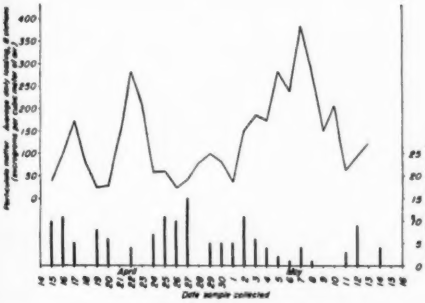

Fig. 12.
Distribution of average daily particulate matter concentration and precipitation (rain, drizzle, snow).

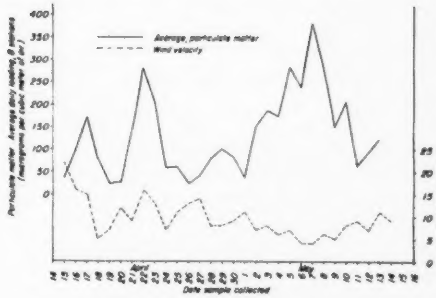

Fig. 13.
Distribution of average daily particulate matter concentration and wind velocity.

ing the constant use of eight sampling units for a one-month period. One motor burned out and was replaced.

As can be readily seen in Table II and Figs. 4 through 11, there was no excessive deviation in particulate matter determined in any one day at the eight stations. Usually, a high or low reading at one station was accompanied by a similar series of readings at the other stations. In all of the plots showing a comparison of one station to an average of eight stations, there was a close similarity in peaks and lows.

The meteorological data collected included wind speed and direction and precipitation (rain, drizzle or snow) by the hour for the entire study period.

Previous study data determined by other investigators has indicated that above average pollution conditions exist when the winds are from a southerly or southwesterly direction and that below average conditions result when the prevailing winds are from the north or northeast. In general, cold air masses accompany north or northeasterly flow and are usually heated by the surface as they move south resulting in turbulence and, by virtue of dilution, less pollution. This condition is described as unstable. Southerly winds are accompanied by the flow of a generally warmer air mass passing over cooler earth surfaces with a consequent increase in stability near the surface. The latter condition of stability usually results in pollution, which is above average.

Rainfall very definitely affected the particulate matter loadings as is shown in Fig. 12, which is a plot of average daily particulate matter and duration (hours) of precipitation. It is believed that increased washing effect and wetting of the ground surfaces resulted in lower air-borne particulate loadings, although little is known concerning the individual effectiveness of either the washing or wetting phenomenon.

As is shown in Fig. 13, which is a plot of average daily particulate matter and wind speed, the data indicate slight correlation of wind speed and air pollution levels.

TABLE III.
SUMMARY* OF CHEMICAL COMPOSITION DETERMINATIONS FOR 22 ELEMENTS (SPECTROGRAPHIC ANALYSIS)

Amount determined in micrograms per cubic meter of air.

Elements	Minimum	Maximum	Median
Aluminum	Absent	6.0	0.75
Iron	Absent	1.4	0.70
Silicon	0.02	8.4	0.80
Calcium	1.5	16.8	9.35
Magnesium	0.01	2.2	0.20
Lead	0.02	8.4	0.80
Zinc	Absent	0.20	0.04
Manganese	0.003	0.10	0.03
Copper	Absent	0.10	0.02
Titanium	Absent	0.80	0.002
Molybdenum	Absent	0.20	0.02
Tin	0.002	0.30	0.01
Nickel	Absent	0.02	0.003
Barium	Absent	0.02	0.002
Chromium	Absent	0.015	0.002
Cadmium	Absent	0.003	0.002
Vanadium	Absent	0.03	0.003
Beryllium	Absent	0.002	Absent
Cobalt	Absent	0.003	Absent
Antimony	Absent	0.10	0.002
Bismuth	0.001	0.10	0.002
Tungsten	Absent	0.10	0.01

*Based on analysis of 60 samples. A total of 240 samples were collected during study (April 15, 1953 to May 15, 1953).

TABLE IV.
COMPARISON OF ST. CLAIR-MARINE CITY AND DETROIT ANALYTICAL DATA (SAMPLES NOT COLLECTED SIMULTANEOUSLY*)

	Amount determined in micrograms per cubic meter of air					
	St. Clair-Marine City			City of Detroit†		
Elements	Minimum	Maximum	Median	Minimum	Maximum	Median
Aluminum	Absent	6.0	0.75	Absent	27.8	2.7
Iron	Absent	1.4	0.70	Absent	17.4	2.4
Silicon	0.002	8.4	0.80	0.04	12.6	2.4
Calcium	1.5	16.8	9.35	0.10	37.9	2.1
Magnesium	0.01	2.2	0.20	0.01	5.3	0.7
Lead	0.02	8.4	0.80	Absent	12.9	0.6
Zinc	Absent	0.20	0.04	Absent	17.9	0.3
Manganese	0.003	0.10	0.03	Trace	2.06	0.14
Copper	Absent	0.10	0.02	Trace	2.67	0.08
Titanium	Absent	0.80	0.002	Absent	0.44	0.03
Molybdenum	Absent	0.20	0.02	Absent	0.51	0.03
Tin	0.002	0.30	0.01	Absent	4.80	0.11
Nickel	Absent	0.02	0.003	Absent	0.07	0.01
Barium	Absent	0.02	0.002	Absent	0.18	0.01
Chromium	Absent	0.015	0.002	Absent	0.26	0.004
Cadmium	Absent	0.003	0.002	Absent	0.089	0.002
Vanadium	Absent	0.03	0.003	Absent	0.042	Absent
Beryllium	Absent	0.002	Absent	Absent	0.018	Absent
Cobalt	Absent	0.003	Absent	Absent	0.017	Absent
Antimony	Absent	0.10	0.002	Absent	0.287	Absent

*St. Clair-Marine City data: April 15, 1953 to May 15, 1953.
City of Detroit data: May 7, 1951 to June 17, 1951.
†Report on 1951 environmental findings, International Joint Commission, Technical Advisory Board on Air Pollution.

Metallic Elements

A GROUP of 60 of the 240 high volume air samples collected were analyzed spectrographically in the laboratories of the Occupational Health Section, U.S. Public Health Service, to identify quantitatively and semiqualitatively, 22 elements.

As is shown in the laboratory findings tabulated in Table III, the predominant elements present were calcium, silicon, aluminum, magnesium, lead and iron.

A comparison with the Detroit study which was run May 7 to June 17, 1951, is shown in Table IV and indicates that the median concentration values determined in Detroit were in most cases appreciably higher than the St. Clair-Marine City results with the exception of lead and calcium. The data do not justify an attempt to pin point the possible industrial sources of some of the metals determined such as lead. Instead, it is merely an indication of the type and extent of pollution in areas having little or no industry in the immediate vicinity.

Tables V, VI and VII list the minimum, maximum, and median values of silicon, iron and aluminum determined at the eight stations with the median particulate mat-

TABLE V.
SILICON- MINIMUM, MAXIMUM, AND MEDIAN VALUES (MICROGRAMS PER CUBIC METER OF AIR)

Station	Total particulate matter collected* (median value)	Silicon		
		Minimum	Maximum	Median
1	156.8	0.2	4.1	0.9
2	91.0	0.3	2.3	0.8
3	97.2	0.1	7.4	0.6
4	100.5	0.1	7.2	2.0
5	85.9	0.02	1.3	0.5
6	58.9	0.2	3.7	0.6
7	118.0	0.1	8.4	0.8
8	164.9	0.5	3.8	1.0

*See Table 1.

TABLE VI.
IRON- MINIMUM, MAXIMUM, AND MEDIAN VALUES (MICROGRAMS PER CUBIC METER OF AIR)

Station	Total particulate matter collected* (median value)	Iron		
		Minimum	Maximum	Median
1	156.8	0.2	0.9	0.8
2	91.0	0.1	0.7	0.8
3	97.2	Absent	0.9	0.4
4	100.5	0.15	7.9	0.9
5	85.9	0.2	1.0	0.4
6	58.9	0.2	0.4	0.9
7	118.0	Absent	1.3	0.3
8	164.9	0.5	0.8	0.7

*See Table I.

Table VII.
Aluminum- Minimum, Maximum, and Median Values (Micrograms per Cubic Meter of Air)

Station	Total particulate matter collected* (median value)	Aluminum		
		Minimum	Maximum	Median
1	156.8	0.09	1.3	1.1
2	91.0	0.1	0.8	1.5
3	97.2	Absent	1.7	0.9
4	100.5	0.3	1.1	6.0
5	85.9	0.09	1.0	0.4
6	58.9	0.2	1.2	0.5
7	118.0	0.2	1.9	0.8
8	164.9	0.5	1.6	1.0

*See Table I.

Table VIII.
Dust Count and Summary- Minimum, Maximum and Median for All Stations

	Minimum	Maximum	Median
Count, in millions of particles per cubic foot of air	0.2	1.2	0.9

Table IX.
Sulfur Dioxide Concentrations Determined at Three Stations Minimum and Maximum Values (Parts per Million)

Station	Date of run	Concentration in parts per million	
		Minimum	Maximum
1	April 15, 1953 to April 22, 1953	0.02	0.06
5	May 1, 1953 to May 14, 1953	0.04	0.07
8	April 22, 1953 to April 27, 1953	0.03	0.08

ter value also being tabulated. There is some, little, or no, correlation with the amounts of particulate matter determined.

Dust Counts

Dust count determinations were made at all stations using the Greenburg-Smith impinger for collection and the Dunn cell for counting. As shown in Table VIII, a median count of 0.9 million particles per cubic foot of air was determined with a minimum value of 0.2, a maximum of 1.2.

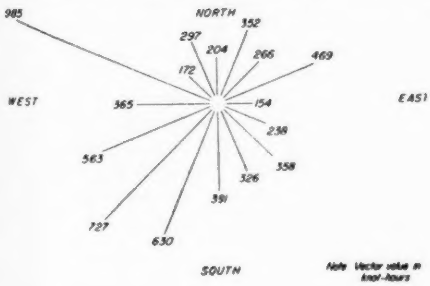

Fig. 14.
Vector analysis of prevailing wind direction based on wind speed and time (knot-hours).

Sulfur Dioxide

The sulfur dioxide concentrations in the St. Clair-Marine City area were of particular importance to this study because of the nature of industry soon to be located there. The extensive Detroit Edison power plant was to consume about 4,800 tons of coal per day. Considering the 3% sulfur content, neighborhood air would be contaminated with more than 130 tons of sulfur gases during 24 hours of operation. In addition, the proposed Michigan Iron and Coke Company would also contribute an extensive volume of sulfur gases.

The Thomas Autometer was used for sampling sulfur dioxide at three of the eight stations, as indicated in Table IX. The concentrations determined ranged from 0.02 to 0.08 parts of SO_2 per million parts of air. Previous study data collected in Detroit[2] during the period May 7 to

Table X.
Comparison of Average Daily Particulate Loading and Prevailing Wind Direction

Date		Particulate matter (Average 8 stations)	Prevailing wind direction
Month	Day		
April	15	39.4	SW
	16	97.4	W
	17	173.6	NW
	18	80.3	W
	19	23.2	NW
	20	27.0	NW
	21	140.8	NW
	22	283.3	SW
	23	207.6	SW
	24	59.2	NE
	25	61.0	SW
	26	23.8	SW
	27	40.5	NW
	28	79.7	NE
	29	80.3	NE
	30	100.4	NE
May	1	82.2	NE
	2	35.9	SE
	3	154.4	SE
	4	191.7	SE
	5	174.8	NE
	6	285.1	NE
	7	239.5	NW
	8	384.6	NW
	9	286.7	S
	10	151.7	SW
	11	208.4	SW
	12	64.4	NW
	13	—	NE
	14	123.5	NE
	15	—	—

June 18, 1951, indicated sulfur dioxide concentrations ranging from 0.05 to 0.10 ppm.

The similarity of results is surprising inasmuch as one area has limited industry and the other (Detroit) an extreme in industrial concentration.

Summary of Findings

1. CITIES having little or no industry exhibit particulate dust loadings approaching levels determined in certain areas of Detroit where a high concentration of industry exists.

2. Country air, often referred to as clean, fresh, invigorating, was found to contain significant quantities of particulate matter.

3. Rainfall had a decided effect on the air-borne particulate matter. The loadings increased with a decrease in precipitation.

4. There is some indication that higher wind speeds result in lower particulate matter loadings by virtue of dilution.

5. The predominant elements determined spectrographically were calcium, silicon, aluminum, magnesium, lead and iron.

6. There is little or no correlation of the amounts of metallic constituents and particulate loadings determined.

7. Dust counts were made at all eight stations indicating a median value of 0.9 million particles per cubic foot of air.

8. Sulfur dioxide concentrations were determined at three sampling stations and ranged from a minimum of 0.02 parts per million to 0.08 parts per million. Previous study data collected in Detroit indicated sulfur dioxide concentrations ranging from 0.05 to 0.10 parts per million.

Although construction has not yet been started on the Michigan Iron and Coke Company and, apparently, is not imminent, the Detroit Edison Company is at the time of this writing operating its plant at about 50% rated capacity.

Study II will include only an evaluation of the Detroit Edison Company's effect on the pollution levels determined in the area and Study III will be a final evaluation based on the operation and contribution of both industrial establishments.

References

1. KEENAN, R. G., and BYERS, D. H.: Rapid Analytical Method for Air Pollution Surveys. *AMA Archives of Indust. Hyg. and Occup. Med.*, 6:226, September, 1952.

2. Report of Results of Sampling Atmosphere in the Detroit River Area During 1951, International Joint Commission.

Recording Audiometric and Noise Exposure Data

IN THE search for data in the study of the relations of hearing loss to noise exposure, it has become evident that no standard method of gathering or recording data is available. In an attempt to rectify this situation, the Subcommittee on Noise in Industry of the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology has prepared a card for recording data which it feels will be applicable to industry in general. A standard card will make it possible to record all the pertinent information necessary to study the relations of hearing loss to noise exposure. The card has been adapted for use with I.B.M. cards, and a standard code has been developed. The Subcommittee hopes that industry will adopt a uniform system of this kind, making it possible to obtain large groups of data. Information regarding the card or the coding system may be obtained by writing to the Director, Subcommittee on Noise in Industry, 111 North Bonnie Brae St., Los Angeles 26, California.

♦ President's Page

THE RELATIVE status of an organization is often measured by its size. Its accomplishments, however, depend on the energy and interest of the membership. The present membership of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION in relation to the total number of people concerned with industrial hygiene puts it in the position of truly representing this field. Its accomplishments may be measured by the prominence and recognition which it now enjoys. The accomplishments of any organization will be limited regardless of its size by the interest, participation, and activities of its members.

Since its formation in 1939, the Association has increased several fold in membership. Along with this have come many and varied responsibilities as related to the field and profession of industrial hygiene. It has been an orderly and natural sequence of events in the total process of "growing up," which the Association has experienced. During this period, such responsibilities have been fully discharged through the able efforts of the officers and directors, combined with support from committees and the membership.

Many people have given generously of their time and effort to insure the future of the Association. Their contributions have not been in vain. However, there is a limit to what can be done on a voluntary basis. In a recent President's Page it was pointed out that AIHA has reached that limit. As a solution to this problem, the Board of Directors has approved the employment of a part-time paid Executive Secretary. This action carries with it responsibilities which the Association has not had in the past.

The functions of the new Executive Secretary have been outlined and coordinated with those of the elected officers and directors. In general, more work and responsibility will be required on the part of the elected Secretary and Treasurer, along with certain committee chairmen. This is not unexpected, but should be duly recognized.

The AIHA will need, in the next few months and years, the interest of every single member. This interest should be in the form of participation in Association affairs as well as financial. There are many ways in which members can give active support to the Association. The officers and directors must conduct the affairs of the Association in accordance with the wishes of the majority of the membership. In order for the officers and directors to know these wishes, it is necessary for members of the Association to attend the annual meetings and take active part in the proceedings. Members should be willing to serve on various committees or accept any other responsibilities which they may be offered.

IN THE APPROACHING period of transition for the Association, certain new policies and procedures will have to be established. It should be realized that experience with these has not been possible in the past so that such policies must be the result of the best judgment at the time. As in any such circumstance, actions may be taken or procedures followed with which some members may disagree. In these cases, constructive suggestions from membership will be welcomed. The value of locally voiced criticism may be lost since it probably would not reach the Association directors.

In a previous President's Page the increase in annual dues was discussed. It was pointed out that this increase has been brought about due to the cost of a paid part-time Executive Secretary. It must be realized that the cost of living for the Association has increased in the same fashion as other costs. The proposed increase in dues is an action already taken by a number of other associations and societies but long delayed by AIHA. These financial obliga-

tions, although new to the Association, should be looked upon as operating cost. The future of the Association will be determined principally by the support of the membership. It may call for a little extra work on the part of all but the cost will be small in comparison to the returns.

—N. V. HENDRICKS

✦ Selected Titles and Abstracts

—FROM FOREIGN EXCHANGE JOURNALS

THE FOLLOWING is a partial list of articles, by titles and authors, from journals received by the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION since the March, 1955, issue of the QUARTERLY in exchange for copies of the QUARTERLY.

Additional information regarding any of the journals or articles may be obtained from: CARROL S. WEIL, Senior Industrial Fellow, Mellon Institute of Industrial Research, 4400 Fifth Avenue, Pittsburgh 13.

I. THE JOURNAL OF SCIENCE OF LABOUR (JAPAN). Vol. 30, No. 8 (1954).

The Threshold Limit of Atmospheric Dust Concentration. Shinji Katsuki, pp. 481 to 488.

The following limits were recommended by the committee on the threshold limit of atmospheric dust concentration: I. Primary threshold: a level above which a healthy man will develop pneumoconiosis (silicosis)—(a) above 10% of free silica, 400 particles per cc, or 8 mg. per m^3 (b) below 10% of free silica, 1000 particles per cc, or 20 mg. per m^3. II. Secondary threshold: a level, above which workers are in danger of contracting silicosis of progressive nature—(a) above 10% of free silica, 400 to 1000 particles per cc, or 8 to 20 mg. per m^3 (b) below 10% of free silica, 2000 particles per cc, or 40 mg. per m^3.

The dust concentration, in Japan, is usually determined with jet dust-counters of the Roken-type (devised by the Institute of Labour) or the Funken-type (devised by the Committee on Dust Control of the Japanese Mining Society).

Relationship Between Silicosis and Tuberculosis, The Comparison of the Autopsy Findings and the Clinical Observation. Tatsuo Sano, pp. 489 to 502.

Studies on Physiologic Action of Carbon Disulfide Vapor. I. The Rate of Absorption and Elimination of CS_2 in Rabbits. Hiromu Kusano, pp. 521 to 530.

II. THE JOURNAL OF SCIENCE OF LABOUR (JAPAN). Vol. 30, No. 9 (1954).

Theoretical Basis of the Maximum Allowable Limit of Dust Concentration of Silica Dust. Siegezi Koshi and Hiroyuki Sakabe, pp. 552 to 564.

On the Change of Auditory Sensitivity Following Exposure to Loud Tones. Mitsuo Morioka and Yoshiaki Ikeda, pp. 565 to 574.

Fatigue in Hot Atmospheric Conditions. I. Change of Physical Functions by Repeated Exposures. Yoshimi Yamagishi, H. Saiki, S. Ishii C. Kim, S. Tokita, Y. Kodama, T. Hoochi and M. Ooba, pp. 575 to 581.

III. THE JOURNAL OF SCIENCE OF LABOUR (JAPAN). Vol. 30, No. 10 (1954).

Fatigue in Hot Atmospheric Conditions. II. Changes of Physicomental Functions by Repeated Exposures. (Author same as for part I—Vol. 30, No. 9.)

Studies in Physiologic Action of Carbon Disulfide Vapor. Part 2. Distribution and Elimination of CS_2 in Tissues of Laboratory Animals. Hiromu Kusano, pp. 645 to 650.

The following conclusions were reached: (1) CS_2 was distributed to the brain, liver, kidneys, heart, lungs, spleen, and adrenals in proportion to the concentration of inhaled CS_2 (which ranged from 60 to 360 ppm for two to three hours). It showed special affinity for tissues rich in fat such as brain, adrenals, and liver. (2) CS_2 was rapidly removed during the first six or seven hours but after that the elimination became relatively slow and not complete by 20 hours. Therefore, the author concluded, the repetition of exposure to the vapor will give rise to toxic effect.

IV. THE JOURNAL OF SCIENCE OF LABOUR (JAPAN). Vol. 30, No. 11 (1954).

Theoretical Basis of the Maximum Allowable Limit of Dust Concentration of Silica Dust. Siegezi Koshi and Hiroyuki Sakabe, pp. 677 to 690.

On the Filter Paper Dust Sampler. Toyohiko Miura and Kikuzi Kimura, pp. 722 to 729.

A description of a hand pump operated filter paper dust sampler. Dust concentration is measured by the use of a photoelectric densitometer.

V. THE JOURNAL OF SCIENCE OF LABOUR (JAPAN). Vol. 30, No. 12 (1954).

Correction Factors for Jet Dust Counter in Regard to Errors Due to Difference of Sampling Air Volumes. Shigeji Koshi, pp. 778 to 780.

Dust particles measured by the jet dust counter vary in their concentration when the samples are taken at different air volumes. This report contains correction factors calculated as functions of measured dust concentration and of sampling air volume.

VI. LA MEDICINA DEL LAVORO (ITALY). Vol. 45, No. 11 (1954).

Occupational Hazard from Toluene: Environmental Investigations and Clinical Research in Chronic Poisoning. L. Parmeggiani and C. Sassi, pp. 574 to 583.

From the results of their studies on workers exposed to from 150 to 1900 ppm of toluene for many years, the authors concluded that the MAC of 200 ppm established by the Governmental Industrial Hygienists is too low. The authors state that workers can tolerate for many years concentrations of toluene up to 300 ppm without hazard to health.

Occupational Poisoning from Paranitroaniline: A Clinical Case with Neuritic Symptoms. G. Baldi and A. Raule, pp. 584 to 589.

Occupational Disease Caused by Sulfuric Acid. A. Raule, pp. 590 to 599.

For persons not accustomed to the acid, the MAC is considered to be about 1 mg./m^3. Those accustomed to it can stand concentrations three to four times higher. Persons chronically exposed may show lesions of the skin (eczematous dermatitis, ulcerations, perionychias), the respiratory tract (tracheobronchitis), the oral cavity (stomatitis), the eyes conjunctivitis), or the digestive tract (gastritis).

VII. LA MEDICINA DEL LAVORO (ITALY). Vol. 45, No. 12 (1954).

Microdetermination of Lead in Air and in Biological Materials by the Titration Method. N. Zurlo and G. Meschia, pp. 668 to 674.

Determination of Quartz in Minerals and Dusts. N. Zurlo and A. M. Griffini, pp. 675 to 690.

Notes on the Determination of Formaldehyde in the Air. N. Zurlo and A. M. Griffini, pp. 692 to 694.

Microdetermination of Mercury in the Air and in Biological Materials. A. M. Griffini and G. C. Gerosa, pp. 695 to 699.

Silicosis Hazard in the Working of Clays. L. Peretti and E. Occella, pp. 700 to 714.

♦ News of Local Sections

Chicago

DR. BROWN, Physicist, Industrial Hygiene Department, Western Electric Company, discussed "Noise Reduction in a Large Industrial Plant" at the January meeting of the Chicago Section. Mr. Brown accompanied his talk with slides showing control measures used and noise reductions attained.

HOWARD N. SCHULZ of Abbott Laboratories, spoke to the Chicago Section at the February meeting. His presentation, "Industrial Hygiene in the Pharmaceutical Industry," was accompanied by interesting slides.

At the March meeting HERBERT WALWORTH, discussed "New Activities of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION."

Northern California

THE NORTHERN CALIFORNIA Section met March 8, at the El Jardin Restaurant, San Francisco. With 64 members and guests present, this was the largest attendance ever at a meeting of this section. The formal part of the meeting featured a discussion by LESTER BRESLOW, M.D., Chief, Bureau of Chronic Diseases, California Department of Public Health. His talk on "Air Pollution," was followed by comments and questions from the audience.

On May 10, the Section held a dinner at the Villa DeLaPaix, Oakland. The speaker was IRVING S. ROSENBLATT, JR.; attorney-at-law, whose subject was "Workmen's Compensation Laws as They Relate to the Handicapped Worker." MR. ROSENBLATT is a graduate of the Harvard Law School and has done much work in the field of Workmen's Compensation.

New Jersey

THE NEW JERSEY Section met at The Hotel Douglas, Newark, April 21. The speaker was MICHAEL A. GIMBEL, Safety Director, Rohm & Haas Company, Bridesburg Division, Philadelphia. MR. GIMBEL'S subject was "Protecting the Worker in Industry" and the presentation was accompanied by slides and a movie taken at the Bridesburg Division. That MR. GIMBEL practices what he advises is substantiated by the 6,458,000 man hours worked at his division since August, 1953, with no lost time.

Nominated for the following offices were: President—MIRIAM SACHS, M.D., New Jersey State Department of Health; President-Elect

—JEROME C. FLATO, Western Electric Company, Kearny; Secretary-Treasurer—DONALD B. ROBINSON, Merck & Company, Rahway; Executive Committee Member—JOHN P. BRADY, Edel Laboratories, Newark.

Southern California

A DINNER MEETING was held by the Southern California Section May 12, at Botwins Restaurant, Los Angeles. General discussion topic was "Industrial Waste Disposal." J. T. NICHOLSON, Division Manager for Southern California Nalco, discussed "Liquid Waste Disposal." "Atmospheric Waste Disposal" was the subject of R. V. SLOAN, Senior Engineer, American Air Filter Company and L. B. SILVERMAN, Chief Health Physics Atomic Energy Project, U.C.L.A. discussed "Radioactive Waste Disposal."

Southern California Section Officers for 1955 are as follows: President—BIRCHARD M. BRUNDAGE, M.D., Atomic Energy Project, U.C.L.A.; President-Elect—PAUL E. CAPLAN, California Dept. of Public Health; Secretary-Treasurer—LOUIS B. SILVERMAN, Atomic Energy Project, U.C.L.A.

Executive Committee members include: Albert L. Chaney, (Past President) Chaney Chemical Laboratory; Harold V. Brown, Division of Occupational Health U.C.L.A.; George Henderson, Mine Safety Appliances Company; and Richard V. Sloan, American Air Filter Company.

St. Louis

THE LAST meeting of the 1954-55 season was held by the St. Louis Section at the Melbourne Hotel on May 31. The speaker was JOHN WAGGETT, Manager of Employee Services, A. P. Green Fire Brick Company, Mexico, Missouri. His subject was "Aluminum Therapy in Silicosis Control."

✦ *In the News*

IEUTENANT COLONEL ALVIN F. MEYER, JR., Chief, Preventive Medicine Branch, Headquarters Strategic Air Command, was recently presented the U.S. Air Force's Commendation Ribbon. The citation accompanying the award read, in part: "COLONEL MEYER distinguished himself by meritorious service as Deputy, Preventive and Industrial Medical Branch, Headquarters Air Materiel Command, from October 10, 1948 to July 15, 1954. As a result of his outstanding ability, foresight and initiative a sound and effective medical and occupational health program for military and civilian personnel of Air Materiel Command has been established. He assisted immeasurably in developing management's awareness of the integrated role of the general invironmental and preventive medical aspects of adverse occupational exposure. His public appearances and professional writings have done much to improve the understanding of Air Force health and sanitation problems. The professional stature he has achieved reflects great credit upon himself, the Air Materiel Command and the United States Air Force."

COLONEL MEYER served in Germany following World War II and upon his return to the United States in October, 1948, was assigned to Air Materiel Command where he was responsible for staff surveillance and technical supervision of the environmental health program. COLONEL MEYER is a member of the American Industrial Hygiene Association.

James Morgan

THE APPOINTMENT of JAMES F. MORGAN to head a section of Industrial Hygiene in the Medical Department of the Pennsylvania Railroad was announced by DR. NORBERT J. ROBERTS, Medical Director. MR. MORGAN was formerly head chemical hygienist of Industrial Hygiene Foundation, Mellon Institute. He is a graduate of George Washington University and engaged in special studies at Georgetown University and the Harvard School of Public Health. As a lieutenant in the Naval Reserve during World War II, he participated in the joint Navy-Maritime Commission shipyard health program under the direction of DR. PHILIP DRINKER. Pennsylvania Railroad is the first American railroad to establish a section of Industrial Hygiene.

Change of Address

THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION announces the appointment of a new Executive Secretary and a change in the business address of the ASSOCIATION. After June 1, 1955, all communications should be directed to:

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION,
GEORGE D. CLAYTON, Executive Secretary,
14125 Prevost,
Detroit 27, Michigan.

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